



GEOLOGICAL SURVEY OF CANADA
PAPER 91-17

**GLACIAL GEOLOGY AND GLACIAL
SEDIMENT GEOCHEMISTRY IN THE CLYDE
FORKS-WESTPORT AREA OF ONTARIO**

I.M. Kettles

1992



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Contribution to Canada-Ontario 1985 Mineral Development
Subsidiary Agreement under the Economic and Regional
Development Agreement. Project funded by the Geological
Survey of Canada.



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Available in Canada through authorized
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or by mail from

Canada Communication Group - Publishing
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

A deposit copy of this publication is also available for reference
in public libraries across Canada

Cat. No. M44-91/17E
ISBN 0-660-14710-6

Price subject to change without notice

Critical Readers

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Original manuscript received: 03-91
Final version approved for publication: 01-92

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GLACIAL GEOLOGY AND GLACIAL SEDIMENT GEOCHEMISTRY IN THE CLYDE FORKS-WESTPORT AREA OF ONTARIO

Abstract

All glacial deposits in the Clyde Forks-Westport area are thought to be Late Wisconsinan or younger. The dominant direction of glacial flow during the Late Wisconsinan was south-southwestward. The most widespread surficial deposit is sandy, stony till. Glaciofluvial sands and gravels are widely distributed, and include deposits associated with three prominent esker-subaqueous fan systems. Laminated glaciolacustrine fine sand and silty clay occur in low-lying areas west of Perth and southeast of Westport. Similar silty clay deposits in the vicinity of Perth and Smiths Falls may be marine.

Regional variations in carbonate content of glacial sediments and till texture reflect most strongly the effects of glacial transport. Concentrations of Paleozoic limestone clasts (2.0-5.6 mm) and clay-sized detritus in till are high overlying Paleozoic terrane in the eastern part of the study region and over an area of Precambrian terrane which extends over 20 km west and southwest of the Paleozoic-Precambrian boundary. Much of the Precambrian terrane is underlain by carbonate-poor lithologies. In contrast, the trace element content of the clay-sized fraction of drift reflects, in most areas, composition of the underlying or nearby bedrock. For example, concentrations of As, Au, Hg, Cu, Pb, and Fe, are high over a major structural zone – the Robertson Lake Mylonite Zone where many known showings of gold and sulphide minerals are known. Further drift prospecting is recommended in the vicinity of the Robertson Lake Mylonite Zone as its mineral potential is largely untested.

Résumé

L'on pense que tous les dépôts glaciaires de la région de Clyde Forks-Westport remontent au Wisconsinien supérieur ou sont plus récents. La direction dominante de l'écoulement glaciaire au Wisconsinien supérieur était le sud-sud-ouest. Le dépôt le plus répandu est un till sablonneux et pierreux. Les sables et graviers fluvio-glaciaires sont présents un peu partout et englobent des dépôts associés à trois remarquables systèmes formés d'eskers et de cônes de déjection subaqueux. Il y a des sables fins et des argiles silteuses glaciolacustres feuilletés dans les étendues basses à l'ouest de Perth et au sud-est de Westport. Les dépôts semblables d'argile silteuse présents aux environs de Perth et de Smith Falls peuvent être d'origine marine.

Les variations régionales de la teneur en roches carbonatées des sédiments glaciaires et de la texture du till reflètent très fortement les effets du transport glaciaire. Les concentrations de fragments (2.0 à 5.6 mm) de calcaire paléozoïque et de drift (de même granulométrie que les argiles) présentes dans le till sont élevées sur le terrane paléozoïque dans la partie orientale de la région à l'étude et sur une région du terrane précambrien s'étendant sur plus de 20 km à l'ouest et au sud-ouest de la limite paléozoïque – précambrienne. Le terrane précambrien repose en grande partie sur des lithologies pauvres en roches carbonatées. Par contraste, la teneur en éléments à l'état de traces de la fraction du drift de même granulométrie que les argiles reflète dans la plupart des régions la composition de la roche en place sous-jacente ou à proximité. Par exemple, les concentrations en As, en Au, en Hg, en Cu, en Pb et en Fe sont élevées sur une zone structurale majeure, la zone mylonitisée du lac Robertson où sont connues un grand nombre de manifestations de minéraux aurifères et sulfurés. Une prospection plus poussée du drift est recommandée dans les environs de la zone mylonitisée du lac Robertson puisque les possibilités minérales de cette zone sont en grande partie non éprouvées.

SUMMARY

The distribution of Quaternary deposits and landforms was mapped and glacial sediments were systematically sampled in four 1:50 000 NTS (National Topographic Series) map sheets – Clyde Forks (31E/02), Sharbot Lake (31C/15), Perth (31C/16), and Westport (31C/09) in eastern Ontario. Sampling was also carried out in the adjacent Tichborne (31C/10) and Carleton Place (31E/01) map areas, and for purposes of discussion, these map areas have been included in the study region (see Fig. 1).

Over 520 drift samples, predominantly till, were collected and analyzed for their content of selected pebble lithologies (2.0–5.6 mm), silt plus clay-sized carbonate (<0.063 mm), and for the following trace elements in the clay-sized (<0.002 m) fraction – Ag, As, Au, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Pd, Pt, U, and Zn. The texture of till samples was also determined. In addition, similar data for approximately 400 glacial sediment samples collected during an earlier survey have been incorporated into the present study. Although the study was designed primarily to aid mineral exploration, the information obtained may be used for evaluating aggregate resources, and as baseline data for assessing sensitivity of the terrain to the effects of environmental hazards such as acid rain.

The eastern half of the study region is underlain by flat-lying Paleozoic limestone, dolostone, shale, and sandstone which lie within the Central St. Lawrence Lowlands. The remainder of the study region is underlain by middle to late Proterozoic rocks of the Central Metasedimentary Belt of the Grenville Province and is part of the Frontenac Arch and Madawaska Highlands physiographic regions. Canadian Shield terrane in this area is characterized by massive outcrops and sharp but low relief.

All surficial deposits are thought to be Late Wisconsinan or younger. Till is the most widespread glacial deposit. Only one stratigraphic unit of till, identified as the Fort Covington Till in the nearby Merrickville area, has been recognized. Till generally forms a thin (<1.5 m), discontinuous cover which rarely masks the structure of the underlying bedrock. Till deposits are thickest (>1.5 m) in drumlinized areas and also in several discontinuous belts. The southernmost and most prominent belt of till forms part of the east-trending Dummer Moraine. Two east-southeast-trending belts, also interpreted as minor recessional moraines, lie south of Westport and Perth.

Glaciofluvial sands and gravels are present commonly in kames, kame terraces, leeside deposits, and eskers. Also common are esker-cored subaqueous fan deposits. One prominent network of discontinuous subaqueous fan deposits extends 75 km north-northeastward from Tamworth to the Poland area while another, oriented southwest-northeast, extends from south

SOMMAIRE

Sur la surface couverte par les quatre feuilles suivantes du Système national de référence cartographique au 1:50 000, les dépôts et les formes de terrain quaternaires ont été cartographiés et les sédiments glaciaires ont été systématiquement échantillonnés. Clyde Forks (31E/02), Sharbot Lake (31C/15), Perth (31C/16) et Westport (31C/09). Un échantillonnage a également été effectué sur la surface adjacente couverte par les cartes de Tichborne (31C/10) et de Carleton Place (31E/01) et à des fins de discussion, la surface couverte par ces cartes a été incluse dans la région d'étude (voir figure 1).

Plus de 520 échantillons de drift principalement du till, ont été recueillis et analysés afin d'en déterminer la lithologie de cailloux choisis (2,0 à 5,6 mm), du silt et des roches carbonatées de même granulométrie que les argiles ($<0,063$ mm); de plus, les éléments à l'état de traces suivants ont été dosés dans la fraction de même granulométrie que les argiles ($<0,002$ mm) – Ag, As, Au, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Pd, Pt, U et Zn. La texture des échantillons de till a également été déterminée. De plus, des données similaires obtenues pour approximativement 400 échantillons de sédiments glaciaires recueillis lors d'un levé antérieur ont été incorporées à la présente étude. Bien que l'étude ait été d'abord conçue de manière à faciliter l'exploration à la recherche de minéraux, l'information obtenue peut être utilisée pour l'évaluation des ressources en granulats et comme information de base pour l'évaluation de la sensibilité du terrain aux effets de dangers environnementaux comme les précipitations acides.

La moitié orientale de la région d'étude repose sur du calcaire, de la dolomie, du shale et du grès gisant à plat dans la partie centrale des basses-terres du Saint-Laurent. Le reste de la région d'étude repose sur les roches du Protérozoïque moyen à supérieur de la zone centrale de roches sédimentaires métamorphisées de la province de Grenville et fait partie des régions physiographiques de l'arche de Frontenac et des hautes-terres de Madawaska. Dans cette région, le terrane du Bouclier canadien est caractérisé par des affleurements massifs et un relief anguleux mais bas.

L'on pense que les dépôts superficiels dateraient du Wisconsinien supérieur ou seraient plus récents. Le till est le dépôt glaciaire le plus répandu. Une seule unité stratigraphique de till, identifiée comme le till de Fort Covington dans la région voisine de Merrickville, a été reconnue. Le till forme généralement une couverture mince ($<1,5$ m), discontinue et qui ne masque que rarement la structure de la roche en place sous-jacente. Les dépôts de till sont les plus épais ($>1,5$ m) dans les régions modelées en drumlins ainsi que dans plusieurs zones discontinues. La zone de till la plus méridionale et la plus remarquable forme une partie de la moraine Dummer s'allongeant vers l'est. Il y a deux zones s'étirant vers le sud-est, également interprétées comme étant des moraines de retrait mineures, au sud de Westport et de Perth.

Les sables et graviers fluvio-glaciaires sont couramment présents sous forme de kames, de terrasses de kame, de dépôts de côté sous le vent et d'eskers. Les dépôts formant des cônes de déjection subaqueux à cœur d'esker sont également communs. Un système remarquable de dépôts discontinus de cône de déjection subaqueux s'étend sur 75 km en direction du nord-nord-ouest, depuis Tamworth jusqu'à la région de Poland

of Elphin over 25 km to the area north of Lanark. A third large complex is located near Charleston Lake. The only subaerial outwash deposit recognized is a large kettle-pocked delta at Joes Lake built within 3 km of the ice margin.

Elsewhere laminated glaciolacustrine fine sand and silty clay occur in low-lying areas northwest and west of Perth and southeast of Westport. Similar deposits near Perth and west of Smiths Falls may be marine. In addition, large areas of the region are covered with organic deposits formed since deglaciation, many of which are contiguous with present day lakes and streams.

Predominant ice flow direction, as evidenced by the orientation of striae and drumlins, was south-southwestward. The presence of the Dummer Moraine and the moraines south of Westport and Perth, suggests that the ice margin was oriented east to east-southeast as the glacier retreated from the area north of Kingston, at least as far north as Perth. During the last stages of glaciation, ice flow was strongly influenced in some places by topography. Locally there was westerly flow, along the Tay River Valley near Perth, in the broad valley south and east of Westport, and in low-lying areas southwest of Bobs Lake in the Tichborne map area. In the northern part of the study region, ice flow patterns were controlled locally by the presence of the Mount St. Patrick escarpment and the northwest-southeast trend of the Ottawa River Valley which lies north of the escarpment. Drumlin and striae orientation change from southwesterly on the southwest side of the escarpment, to southerly on the east side of the escarpment, to southeasterly north of the escarpment and in the Carleton Place region. Both older southwestward- and younger southeastward-trending striae are present north of the escarpment and farther north in the Ottawa Valley (see also Gadd, 1980).

The wide distribution of subaqueous outwash fan deposits and blanket deposits of laminated silty clay and fine sand well outside projected marine limits (see also Henderson, 1973), indicate that proglacial lakes abutted the ice margin as the ice retreated. Several types of evidence suggest that as far north as Ompah and Clyde Forks, the proglacial waters abutting the retreating ice margin originated in the Lake Ontario basin. First, based on projection of the known maximum Iroquois water plane from Pancake Hill 40 km west of the study region into the study region, there are no topographic barriers to prevent flooding. Also, the presence of east- to east-southeast-trending recessional moraines implies that flooding was not impeded by the presence of a minor ice lobe. Second, the ostracod, *Candona subtriangularulata*, was discovered in laminated silty clay (C. Rodrigues, pers. comm., 1990), at six scattered sites including two near Ompah and Clyde Forks. This species is known to occur only in large, oligotrophic lakes with few dissolved solids. Third, *Mysis relicta*, a fresh or brackish water shrimp, was previously found in some lakes of the region

et un autre, orienté sud-ouest nord-est s'étend du sud d'Elphin sur 25 km jusqu'à la région située au nord de Lanark. Un troisième grand complexe est situé près du lac Charleston. Le seul dépôt fluvio-glaciaire subaérien reconnu est un grand delta marqué de kettles à Joes Lake qui a été édifié à moins de 3 km de la marge glaciaire.

Il y a ailleurs des sables fins et des argiles silteuses glaciolacustres feuilletées dans les étendues basses au nord-ouest et à l'ouest de Perth ainsi qu'au sud-ouest de Westport. De similaires dépôts à proximité de Perth et à l'ouest de Smith Falls peuvent être d'origine marine. De plus, de grandes étendues de la région sont recouvertes de dépôts organiques formés depuis la déglaciation et dont un grand nombre sont contigus aux actuels lacs et cours d'eau.

Comme l'indique l'orientation des stries et des drumlins, l'orientation dominante de l'écoulement de la glace était le sud-sud-ouest. La présence de la moraine Dummer et des moraines au sud de Westport et de Perth suggère que la marge glaciaire était orientée en direction est à est-sud-est alors que le glacier reculait depuis la région de Kingston au moins jusqu'à Perth au nord. Pendant les derniers stades de la glaciation, l'écoulement de la glace était en certains endroits fortement influencé par la topographie. Il y a eu, par endroits, un écoulement vers l'ouest, le long de la vallée de la rivière Tay près de Perth, dans la large vallée au sud et à l'est de Westport et dans des étendues basses au sud-ouest de Bobs Lake de la région couverte par la carte de Tichborne. Dans la partie septentrionale de la région d'étude, les configurations de l'écoulement de la glace étaient localement déterminées par la présence de l'escarpement Mount St. Patrick et l'orientation nord-ouest sud-est de la vallée de la rivière des Outaouais qui se trouve au nord de cet escarpement. L'orientation des drumlins et des stries passe du sud-ouest, qu'elle était du côté sud-ouest de l'escarpement, au sud du côté est de l'escarpement, puis au sud-est au nord de l'escarpement et dans la région de Carleton Place. Des stries plus anciennes orientées au sud-ouest ainsi que des stries plus jeunes orientées au sud-est sont présentes au nord de l'escarpement et plus loin au nord dans la vallée de l'Outaouais (voir également Gadd, 1980).

Les très répandus dépôts de cônes de déjection fluvio-glaciaires subaqueux et les couvertures d'argile silteuse et de sable fin bien à l'extérieur des limites marines projetées (voir également Henderson, 1973) indiquent que des lacs proglaciaires s'appuyaient sur la marge glaciaire en recul. Plusieurs types d'indices suggèrent que jusqu'à Ompah et à Clyde Forks en direction du nord, les étendues d'eau proglaciaires appuyées à la marge glaciaire en recul tiraient leur origine du bassin du lac Ontario. Premièrement, d'après la projection de l'étendue maximale connue du plan d'eau Iroquois, depuis la colline Pancake à 40 km à l'ouest de la région d'étude jusque dans la région d'étude, aucune barrière topographique n'aurait pu empêcher que la région soit noyée. De plus, la présence des moraines de retrait d'orientation est à est-sud-est implique qu'aucun lobe glaciaire mineur ne nuisait à l'inondation. Deuxièmement, l'ostracode *Candona subtriangularulata* a été découvert dans l'argile silteuse feuilletée (C. Rodrigues, comm. pers., 1990) en six emplacements épars dont deux à proximité d'Ompah et de Clyde Forks. L'on sait que cette espèce ne fréquente que les grands lacs oligotrophes à faible teneur de matières solides dissoutes. Troisièmement, *Mysis relicta*, une

(Dadswell, 1974). This species is expected to occur, in this part of eastern Canada, only in those lake basins which were flooded by Late Wisconsinan proglacial lakes originating in the Great Lakes basin.

Two Ontario basin proglacial lakes were recognized from locations of shoreline features and occurrences of *Candona subtriangulata* and *Mysis relicta*. A phase with a level of over 289 m a.s.l. near Ompah, interpreted to be Lake Iroquois, was identified. Another with a maximum level between 198-213 m a.s.l. in the Clyde River Valley 25 km northeast of Ompah is thought to be one of the lower post-Lake Iroquois phases. Insufficient information was obtained to correlate the second lower lake with post-Lake Iroquois phases known to have existed in the Lake Ontario basin.

Coleman (1901) and E.P. Henderson (pers. comm., 1989) found whale bones and marine shells, respectively, near Smiths Falls indicating that the Champlain Sea covered part of the Perth map area. No other paleontological or sedimentological data that could be used to determine limits of marine incursion were found as part of this study. On the basis of locations of marine shell-bearing shoreline features at or near marine limit in the Carleton Place area (Richard, 1990) and waterplane projections, a marine limit was established which crosses the Perth area at 137 m a.s.l.

Study of pebble lithology of glacial sediments (2.0-5.6 mm) indicates that glacial dispersal can be observed at two scales – regional (tens of kilometres) and local (1-2 km) in the study region. The distribution of Paleozoic carbonate clasts in drift reflects the effects of glacial transport at a regional scale. Concentration of Paleozoic carbonate clasts is high (>60%) over Paleozoic bedrock and over an area of Precambrian terrane which extends over 20 km west and southwest of the Precambrian-Paleozoic boundary (>20%). Results of an earlier glacial sediment sampling programme which encompassed the present study region indicate that traces of Paleozoic carbonate may still be detected in drift overlying Precambrian terrane over 70 km west of the Paleozoic-Precambrian boundary. Large quantities of debris derived from the easily-eroded Paleozoic dolostone and limestone which underlie both the eastern part of the study area and also a large area farther east were incorporated into the glacier and transported southwestward. In contrast, highest concentrations of clasts of Precambrian lithologies are found close to the outcrop areas of each bedrock type. The production of weak dispersal trains from Precambrian crystalline lithologies likely reflects low sediment production from these massive, hard, coarse grained strata.

crevette fréquentant les eaux douces ou saumâtres, a antérieurement été découverte dans certains lacs de la région (Dadswell, 1974). On ne s'attend à trouver cette espèce, dans cette partie du Canada oriental, que dans les bassins lacustres qui ont été noyés par des lacs proglaciaires du Wisconsinien supérieur ayant leur origine dans le bassin des Grands Lacs.

D'après les emplacements d'entités de lignes de rivages et les découvertes de *Candona subtriangulata* et de *Mysis relicta*, deux bassins de lacs proglaciaires ont été reconnus en Ontario. Une phase dont le niveau atteint plus de 289 m a.n.m. près d'Ompah, interprétée comme étant le lac Iroquois, a été identifiée. Une autre, dont le niveau maximum se situe entre 198 et 213 m a.n.m., dans la vallée de la rivière Clyde à 25 km au nord-est d'Ompah, serait l'une des phases de niveau inférieur postérieure au lac Iroquois. L'information obtenue a été insuffisante pour mettre en corrélation le deuxième lac de niveau inférieur avec les phases postérieures au lac Iroquois dont l'existence est connue dans le bassin du lac Ontario.

Coleman (1901) et E.P. Henderson (comm. pers., 1989) ont respectivement trouvé des os de baleines et des coquillages marins, à proximité de Smith Falls, ce qui indique que la mer de Champlain recouvrait une partie de la région de la carte de Perth. Aucune autre donnée paléontologique ou sédimentologique qui permettrait de déterminer les limites de l'incursion marine n'a été découverte dans le cadre de la présente étude. D'après l'estimation des niveaux des plans d'eau et les emplacements des entités de ligne de rivage renfermant des coquillages marins à la limite marine dans la région de Carleton Place ou à proximité de cette dernière (Richards, 1990), une limite marine traversant la région de Perth a été projetée à 137 m a.n.m.

L'étude de la lithologie des cailloux (2.0 à 5.6 mm) des sédiments glaciaires indique que la dispersion glaciaire peut être observée à deux échelles : à l'échelle régionale (dizaines de kilomètres) et à l'échelle locale (1 à 2 km) dans la région d'étude. La distribution des fragments de roches carbonatées du Paléozoïque dans le drift reflète les effets du transport glaciaire à l'échelle régionale. La concentration de fragments de roches carbonatées du Paléozoïque est élevée (> 60 %) sur la roche en place paléozoïque et sur une région du terrane précambrien s'étendant sur plus de 20 km à l'ouest et au sud-ouest de la limite paléozoïque – précambrienne (> 20 %). Les résultats d'un programme antérieur d'échantillonnage des sédiments glaciaires ayant englobé la région d'étude indiquent que des traces de roches carbonatées du Paléozoïque peuvent encore être détectées dans les matériaux détritiques recouvrant le terrane précambrien à plus de 70 km à l'ouest de la limite paléozoïque – précambrienne. De grandes quantités de débris dérivés de la dolomie et du calcaire paléozoïques facilement érodables sous-jacents à la partie orientale de la région d'étude et à une grande étendue plus loin à l'est ont été incorporées au glacier et transportées vers le sud-ouest. Par contraste, les concentrations les plus élevées de fragments de lithologies précambriennes se retrouvent à proximité des régions affleurantes de chaque type de roche en place. La production de maigres traînées de dispersion derrière les lithologies précambriennes cristallines reflète vraisemblablement une faible production de sédiments par ces couches massives et dures de granulométrie grossière.

Regional variations in the content of silt plus clay-sized carbonate (<0.063 mm) in glacial sediments and the texture of till also reflect the effects of glacial transport. Over Paleozoic terrane and over the area of Canadian Shield terrane west and southwest of the Paleozoic-Precambrian boundary where glacial sediments have high concentrations of Paleozoic clasts, glacial sediments are also enriched in silt plus clay-sized carbonate (commonly >15% CaCO_3 equivalent) and the till is generally more fine grained. Silt plus clay-sized carbonate levels are especially high (>50% CaCO_3 equivalent) in glacial sediments that are also enriched in Precambrian marble clasts and overlie two large Precambrian marble belts, one in the McDonalds Corners area and another south of Ompah.

Trace element content of drift is most strongly influenced by the composition of underlying or nearby bedrock. Trace element levels in drift overlying Paleozoic lithologies are generally lower than those in glacial sediments overlying Precambrian bedrock. In the study area, levels of most trace elements in drift are highest overlying those parts of the Central Metasedimentary Belt which lie within the Clyde Forks and Sharbot Lake map areas. Some enrichment in drift likely reflects high background concentrations of trace elements in the underlying bedrock of these map areas. For example, Zn and Cd enrichment correspond closely to each other and to Precambrian marble clast enrichment in drift and Precambrian marble outcrop areas. High levels of some trace elements in glacial sediments may also reflect mineralization in the underlying bedrock. Concentrations of As, Au, Hg, Cu, Pb, and Fe, for example, are high over a major structure – the Robertson Lake Mylonite Zone, where many showings of gold and other sulphide minerals have been discovered.

In other cases, some chemical variation in drift composition can be related to sediment facies sampled (Kettles and Shilts, 1989) or the sample fraction analyzed (Shilts, 1973, 1984b). In contrast to the other trace elements, Au in drift was determined for the silt plus clay-sized rather than the clay-sized fraction of drift samples. The distribution pattern of glacial sediments with low levels of Au seem to mimic particularly closely the distribution patterns of drift with high levels of silt plus clay-sized carbonate. This suggests that in some areas, the Au abundance in drift was suppressed by large concentrations of Au-poor Paleozoic carbonate in the fine fractions of glacial sediments. Also, there is a wide range of trace element concentration in samples of till and glaciofluvial ice contact sand and gravel compared to those collected in glaciolacustrine and glaciomarine silty clay. Compositional variability in the former two sediment types is likely strongly influenced by local

Des variation régionales de la teneur en silt et en roches carbonatées de même granulométrie que les argiles (<0.063 mm) dans les sédiments glaciaires et de la texture du till reflètent également les effets du transport glaciaire. Sur le terrane paléozoïque et sur la région du terrane du Bouclier canadien à l'ouest et au sud-ouest de la limite paléozoïque – précambrienne où les sédiments glaciaires présentent des concentrations élevées en fragments paléozoïques, les sédiments glaciaires sont également enrichis en silt et en roches carbonatées de même granulométrie que les argiles (couramment > 15 % d'équivalent de CaCO_3) et le till est généralement de granulométrie plus fine. Les concentrations en silt et en roches carbonatées de même granulométrie que les argiles sont particulièrement élevées (plus de 50 % d'équivalent de CaCO_3) dans les sédiments glaciaires qui sont également enrichis en fragments de marbre précambrien et qui recouvrent deux grandes zones de marbre précambrien, l'une dans la région de McDonalds Corners et l'autre au sud d'Ompah.

La teneur en éléments à l'état de traces du drift est de plus fortement influencée par la composition du socle rocheux sous-jacent ou à proximité. Les concentrations d'éléments à l'état de traces dans le drift recouvrant les lithologies paléozoïques sont généralement inférieures à celles observées dans les sédiments glaciaires recouvrant la roche en place précambrienne. Dans la région d'étude, les concentrations de la plupart des éléments à l'état de traces dans le drift sont les plus élevées au-dessus des parties de la zone centrale de roches sédimentaires métamorphisées qui se trouvent à l'intérieur des étendues couvertes par les cartes de Clyde Forks et de Sharbot Lake. Un certain enrichissement du drift reflète vraisemblablement des concentrations de fond élevées en éléments à l'état de traces dans la roche en place sous-jacente des régions couvertes par ces cartes. Par exemple, des enrichissements en Zn et en Cu correspondent étroitement les uns avec les autres et avec l'enrichissement en fragments de marbre précambrien dans le drift et les régions des affleurements de marbre précambrien. Des concentrations élevées de certains éléments à l'état de traces dans les sédiments glaciaires peuvent également refléter la minéralisation de la roche en place sous-jacente. Par exemple, les concentrations en As, en Au, en Hg, en Cu, en Pb et en Fe sont élevées au-dessus d'une structure majeure, la zone mylonitisée du lac Robertson où ont été découvertes un grand nombre de manifestations de minéraux aurifères et sulfurés.

Dans d'autres cas, une certaine variation de la composition chimique du drift peut être associée aux faciès des sédiments échantillonnés (Kettles et Shilts, 1989) ou à la fraction analysée de l'échantillon (Shilts, 1973, 1984b). Par contraste avec les autres éléments à l'état de traces, l'Au dans le drift a été dosé dans la fraction du silt plus les matériaux de même granulométrie que les argiles plutôt que dans la fraction des matériaux de même granulométrie que les argiles uniquement dans les échantillons de drift. La configuration de la distribution des sédiments glaciaires présentant de faibles concentrations d'Au semble correspondre particulièrement étroitement avec les configurations des distributions du drift présentant des concentrations élevées en silt et en roches carbonatées de même granulométrie que les argiles. Cela suggère que dans certaines régions, l'abondance de l'Au dans le drift a été supprimée par de grandes concentrations de roches carbonatées paléozoïques pauvres en Au dans les fractions fines des sédiments glaciaires. De plus, les plages de

variability in bedrock lithologies either at or up-ice from the sample site, whereas lack of compositional variation in the latter two types may reflect homogenization associated with their deposition (Kettles and Shilts, 1989).

Some chemical variation in the trace element composition of glacial sediments may also result from postglacial weathering (Kettles and Shilts, 1989). In individual samples, concentrations of Fe, sometimes Mn, and commonly other trace elements, are high in samples of glacial sediments that were described in the field as being highly weathered. In addition, glaciofluvial sands and gravels generally have, on average, higher trace element concentrations in the clay fraction than do samples of till collected nearby. Because the fines have been removed from these sediments by fluvial reworking prior to deposition, it is likely that a large part of the clay-sized minerals in these sediments were formed during weathering, and many of these are metal-enriched.

As previously mentioned, concentrations of Au, Cu, Zn, and other trace elements were commonly high in drift collected over or close to the Robertson Lake Mylonite Zone where gold and base metal occurrences in bedrock are known. Levels are particularly high in drift in the southern part of the Clyde Forks map area, in the northwest corners of the Sharbot Lake and Tichborne map areas, and in the Pennick Lake area, 8 km north of Sharbot Lake. Further drift prospecting work is recommended in the vicinity of the Robertson Lake Mylonite Zone. Few samples were collected because road access is generally poor, and, as a result, the mineral potential of this promising area is largely untested.

concentrations d'éléments à l'état de traces sont étendues dans les échantillons de till et de sables et graviers fluvio-glaciaires de contact glaciaire, comparativement à celles des échantillons recueillis dans l'argile silteuse glaciolacustre et glaciomarine. La variabilité de la composition des deux premiers types de sédiments est vraisemblablement fortement influencée par la variabilité locale des lithologies de la roche en place à l'emplacement d'échantillonnage ou à l'amont de ce dernier par rapport à l'écoulement glaciaire, alors que l'absence de variation de la composition dans les deux derniers types de sédiments peut refléter une homogénéisation associée à leur dépôt (Kettles et Shilts, 1989).

Une certaine variation de la composition en éléments à l'état de traces des sédiments glaciaires peut également résulter de l'altération postglaciaire (Kettles et Shilts, 1989). Dans des échantillons individuels, les concentrations en Fe, parfois en Mn, et couramment en d'autres éléments à l'état de traces sont élevées dans les sédiments glaciaires qui ont été décrits sur le terrain comme étant très altérés. De plus, la fraction de même granulométrie que les argiles des sables et graviers fluvio-glaciaires présente en général, en moyenne, des concentrations en éléments à l'état de traces plus élevées que les échantillons de till recueillis à proximité. Puisque les fines ont été retirées de ces sédiments par remaniement fluvial avant leur dépôt, il est vraisemblable qu'une part importante des minéraux de même granulométrie que les argiles dans ces sédiments se soient formés pendant leur altération et un grand nombre de ces minéraux sont enrichis en métaux.

Tel que mentionné précédemment, les concentrations en Au, en Cu, en Zn et en autres éléments à l'état de traces étaient couramment élevées dans le drift recueilli au-dessus ou à proximité de la zone mylonitisée du lac Robertson où sont connues des manifestations d'or et de métaux communs dans la roche en place. Les concentrations sont particulièrement élevées dans la partie méridionale de la surface couverte par la carte de Clyde Forks, aux angles nord-ouest de la surface couverte par les cartes de Sharbot Lake et de Tichborne et dans la région du lac Pennick à huit kilomètres au nord de Sharbot Lake. Une prospection plus poussée du drift est recommandée dans les environs de la zone mylonitisée du lac Robertson. Peu d'échantillons ont été recueillis parce que l'accès routier est généralement mauvais et il en résulte que les possibilités minérales de cette région prometteuse sont en grande partie non éprouvées.

INTRODUCTION

A program of surficial geological mapping and systematic glacial sediment sampling was undertaken in eastern Ontario as part of the Canada-Ontario Mineral Development Agreement (1985-1990) (Fig. 1, 2). This report describes both the distribution and some physical and chemical characteristics of Quaternary deposits in the Clyde Forks-Westport region. Four Quaternary deposits maps at 1:50 000 scale for the Clyde Forks (31F/02), Sharbot Lake (31C/15), Perth (31C/16), and Westport (31C/09) regions are included as a pocket item accompanying this report. For purposes of discussion, the contiguous map areas of Carleton Place (31F/01) (Richard, 1990) and Tichborne (31C/10) (Henderson, 1973) have been included in the study region.

Field mapping and sampling were carried out by the author and P.J. Henderson in the Westport area in 1986, by the author in the Perth and Clyde Forks areas in 1988, and by P.J. Henderson in the Sharbot Lake area in 1988. Sample locations, data lists, statistical information, and maps showing regional variation in trace element, carbonate, and textural composition of glacial sediments have been released as Geological Survey of Canada, Open File 2274 (Kettles, 1990).

Location and physiography

The study area (Fig. 1, 2, 3), about 50 km south of Ottawa, covers the six 1:50 000 NTS (National Topographic Series) map sheets listed above (Fig. 1). The region lies within latitude 44°30'N and 45°15'N and longitude 76°W and 77°W, covers a total area of 6500 km², and includes parts of Lanark, Frontenac, and Leeds counties. The Ottawa River-Lake Ontario and St. Lawrence River drainage divide crosses the study area north of Westport (Fig. 1). All important place names are shown on Figures 1 to 3.

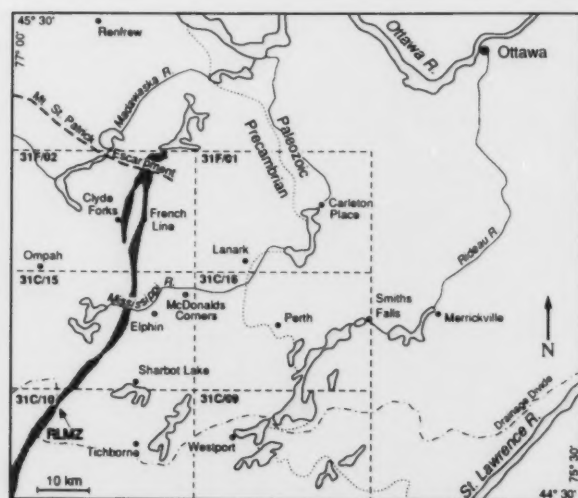


Figure 1. Location of the Clyde Forks-Westport study area. Also shown is the Robertson Lake Mylonite Zone (RLMZ).

The eastern half of the study region, which is underlain by flat-lying Paleozoic sedimentary rocks, is part of the St. Lawrence Lowlands physiographic region (Bostock, 1970) (Fig. 2). The remainder of the study region, underlain by Precambrian crystalline bedrock, lies within parts of the Frontenac Arch and Madawaska Highlands physiographic regions (Bostock, 1970; Freeman, 1979). The Frontenac Axis is a prominent geological structure which connects the main body of the Canadian Shield in the north to the Adirondack Mountains south of the St. Lawrence River in New York state. The northern edge of the Madawaska Highlands is marked by the Mount St. Patrick escarpment which follows a southeast-trending fault associated with the Ottawa-Bonnechere Graben (Kay, 1942).

Objectives

This study was designed primarily to support mineral exploration. It is the second programme of systematic glacial sediment sampling carried out in this region within the past 10 years. The first sampling program was designed to quantify regional variation in drift composition in order to provide baseline data for assessing the sensitivity of the terrain to the effects of acid rain (Shilts, 1981, 1984a; Kettles and Shilts, 1989) (Fig. 4). As part of the original project, drift samples from over 2500 sites on the Canadian Shield between Ottawa and Georgian Bay in Ontario and in the Gatineau Valley region of southwestern Quebec (Kettles and Shilts, 1983; Kettles, 1988a, b) were collected and analyzed. Clyde Forks and surrounding areas were selected for further investigations because results of the original study showed that drift in the Clyde Forks and Sharbot Lake area is commonly metal-enriched, and numerous sites with high concentrations of Au, U, and base metals in bedrock are known (Carter et al., 1980; Sangster, 1982).

One of the main objectives of the present study was to provide maps of Quaternary geology. Information pertaining to ice flow history and glacial sediment distribution obtained from surficial mapping can provide a framework within which geochemical and other compositional data can be interpreted. Another primary objective was to delineate, in more detail, areas of metal-enriched drift and their bedrock sources. To accomplish this goal, 520 samples, most of till, have been collected since 1986 and analyzed for trace elements, carbonate, texture, and content of selected pebble lithologies. In addition, similar data for approximately 400 samples collected during the original survey (Kettles and Shilts, 1983) have been incorporated into the present study.

Two lesser objectives were also outlined. The first was to expand the knowledge of Quaternary history. Details of the glacial history of eastern Ontario, at present sparse, are significant because the area lies within the region where proglacial lakes impounded in the isostatically depressed Lake Ontario basin interacted with the Champlain Sea. The second is to continue to map in more detail, the contents of carbonate and fine grained detritus in drift, the components that can buffer acid rain. The study region, which includes the historic Rideau River and canal system, is an important cottage and water sport-based recreational area. Because

much of the Clyde Forks-Westport area is underlain by carbonate-poor crystalline bedrock and drift cover is thin, it is potentially sensitive to the effects of acid rain.

Previous work

Chapman and Putnam (1966) described the physiography of the study area. Henderson (1967, 1973) published a preliminary Quaternary map of the Westport area (31C/09) and a large scale surficial geology map of the Kingston (31C, N1/2) region, including the Sharbot Lake, Perth, and Westport map areas. Quaternary mapping has been carried out in the adjoining 1:50 000 scale map areas of Renfrew (Barnett and Clarke, 1980), Arnprior (Richard, 1984), Carleton Place (Richard, 1990), Merrickville (Sharpe, 1979), and Brockville (Henderson, 1970).

Numerous researchers have examined spatial and temporal relationships among Late Quaternary glacial Lake Iroquois, later lower lake phases occupying the Ontario basin, and the Champlain Sea. From detailed field mapping of strandline features, Spencer (1890) defined the broad outlines of Lake Iroquois. Coleman (1904, 1936) produced detailed maps of the Iroquois shoreline, incorporating information from one of the earliest Quaternary investigations in the project area (Coleman, 1901). In Ontario west

of the study region, Miryneck (1962, 1967) mapped short-line phenomena in the Trent River Valley, and Leyland (1984) in the Trenton-Belleville area. Lake Iroquois was traced to a maximum elevation of 222.5 m at Pancake Hill 17 km southeast of Madoc (Coleman, 1936; Miryneck, 1962). East of Madoc, Lake Iroquois is known to have expanded as far north as the Dummer Moraine (Henderson, 1973) but its northern limit was not defined. Anderson et al. (1985), Anderson and Lewis (1985), and Rodrigues (1988) have analyzed microfaunal assemblages in sediment cores from the Central St. Lawrence Lowlands, to reconstruct environments of deposition during late glacial times. Using their own and other available shoreline information, Anderson and Lewis (1985) reconstructed Lake Ontario basin paleowater planes while Muller and Prest (1985) reviewed the glaciolacustrine history of the Ontario basin. Muller and Prest (1985) found evidence for the Iroquois shore at 285 m a.s.l. at Cloyne, 6 km southwest of Ompah. They also noted an isobase trend of N100°E and an uplift gradient of 1.6 m/km in the Belleville area.

There are two views of the style of ice retreat from the study area and surrounding regions in southeastern Ontario. In diagrams depicting the late glacial history, Chapman and Putnam (1966) and Prest (1970) showed a nearly linear east-trending margin on the mass of ice retreating in the area north of Kingston. They based this interpretation on the

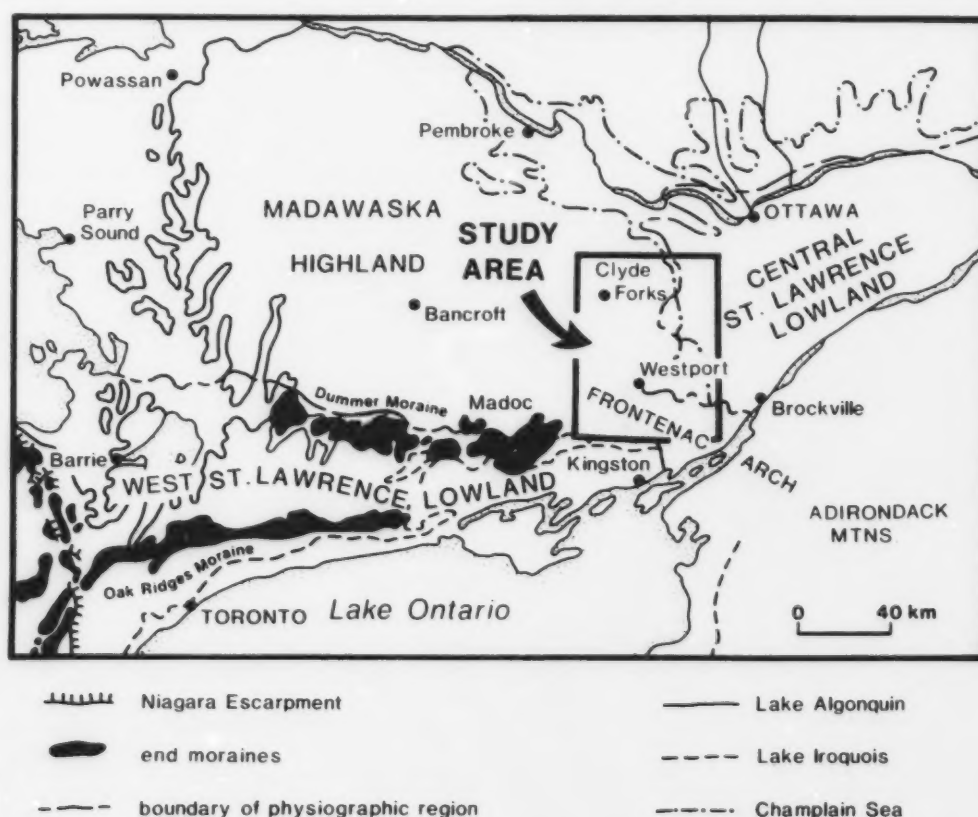
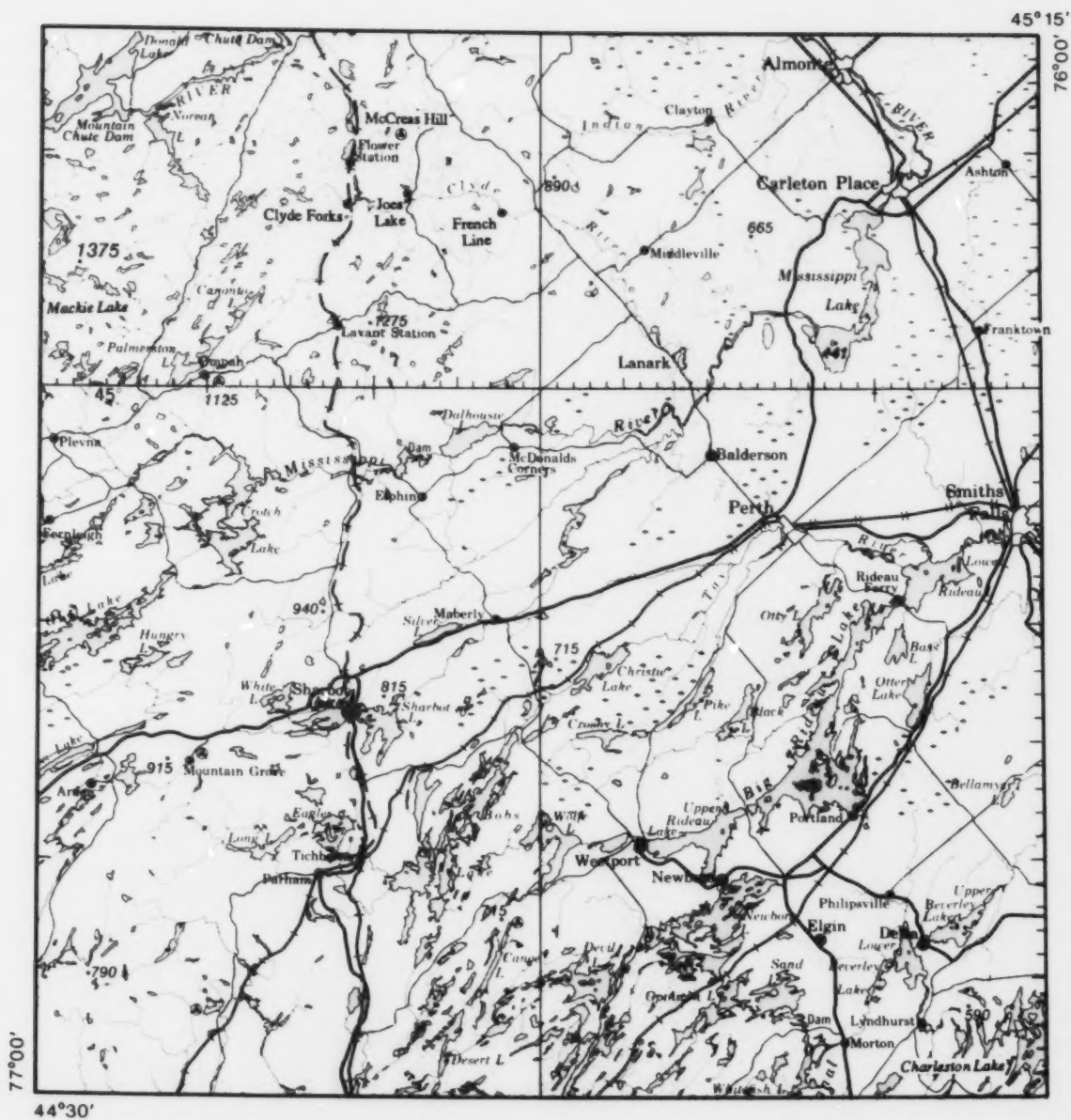


Figure 2. Physiography of the Clyde Forks-Westport area and surrounding regions of southeastern Ontario.



INDEX MAP

Figure 3. Geography of the Clyde Forks-Westport study area.

20 km

east trend of the Dummer Moraine which they considered a recessional moraine. Later, Gadd (1980) concluded that the Dummer Moraine was not a recessional moraine, having decided that its morphology was more closely related to bedrock structure than to deposition of glacial sediments. On the basis of reconnaissance field mapping, Gadd (1980) postulated that there were two late glacial ice lobes in the area north of Lake Ontario and developed the concept of a calving bay in the Ottawa Valley during early Champlain Sea time. He also recognized an interlobate zone separating the two lobes that included the Oak Ridges Moraine and also the long network of glaciofluvial deposits which extend in the present study region northeastward from Tamworth (see Fig. 12 and Ice contact sediments section).

A number of regional surveys undertaken in south-eastern Ontario covered the study area. Systematic sampling of lake sediments and lake waters (Hornbrook et al., 1984a) and of glacial sediments (Kettles and Shilts, 1983) were conducted for mineral exploration and environmental purposes, respectively (Fig. 4). Airborne radioactivity maps and profiles for the region have been released as Geological Survey of Canada, Open File 331, (1976) and 428, (1977).

Acknowledgments

The author wishes to thank Julie Cousineau for her able assistance in the field in 1987 and 1988, P.J. Henderson for collecting samples in the Sharbot Lake area, C.G. Rodrigues (University of Windsor) for his paleontological work on many samples collected in the study area, K.A. Laurus for carrying out pebble lithology work, P.J. Higgins and M.H.M. Wyergangs for laboratory assistance, S. Courtney and P.H. Wyatt for computer assistance, R. Easton for information pertaining to the bedrock of the area, B. Pudney and J. Cousineau for assistance preparing the maps, and the following for helpful discussions: P.J. Henderson, J.R. Hill, C.A. Kaszycki, R.J. Fulton, V.K. Prest, D.R. Sharpe, H.L. Thorleifson, G.A. Gorrell, V.N. Rampton, and T.W. Anderson. The manuscript was improved after critical review by P.J. Barnett, R.N.W. DiLabio, and W.W. Shilts.

The author also extends her thanks to the residents of the area who permitted access to their land. Special thanks go to T. Cavanagh, the Tackaberry family, Mrs. J. Poole, and J. Playfair for allowing unlimited access to their gravel pits.

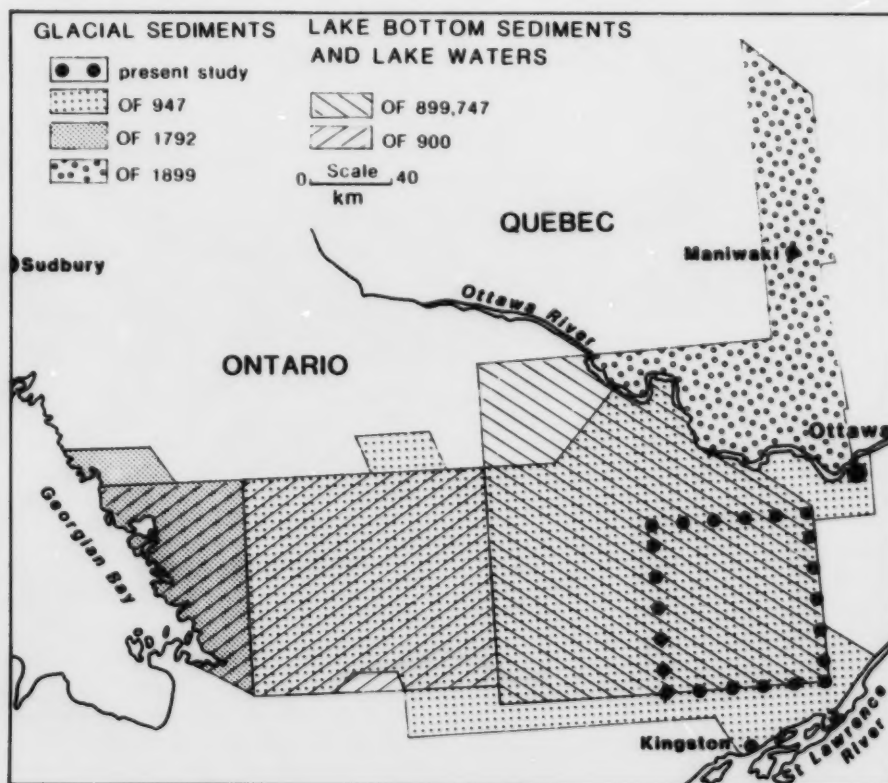


Figure 4. Areas covered by the following sampling surveys: (1) glacial sediments — Geological Survey of Canada, Open Files 947 (Kettles and Shilts, 1983), 1792 (Kettles, 1988a), 1899 (Kettles, 1988b) and (2) lacustrine sediments and lake waters — Geological Survey of Canada, Open Files 747 (Geological Survey of Canada, Mineral Resources Division, 1981), 899 (Hornbrook et al., 1984a), and 900 (Hornbrook et al., 1984b).

METHODS OF INVESTIGATION

Field methods

Surficial deposits were mapped by four-wheel drive vehicle traverses along roads and trails. Field information was supplemented by study of aerial photographs at scales of 1:15 000 and 1:40 000.

Till and other drift samples were dug to determine sediment type, by shovel or hand auger from natural or man-made exposures along roads and streams as well as from sand and gravel pits. Care was taken to collect materials from below the solum, except in the best exposures of till, where samples were collected in profile over the entire exposure.

Laboratory methods

The clay-sized (<0.002 mm) fraction of till, silty clay and some sand and gravel samples was separated by centrifuging and decanting and analyzed for selected trace and minor elements — Cu, Pb, Zn, Co, Ni, Ag, Cr, U, Mo, Mn, Fe, Cd, As, and Hg, after leaching with hot aqua regia. All elements were analyzed by atomic absorption, except U and As, which were analyzed by fluorometry and colorimetry, respectively. Samples were analyzed by Bondar-Clegg and Co. Ltd., Ottawa, and Chemex Labs Ltd., Vancouver.

Gold, Pd, and Pt content of the silt plus clay (<0.063 mm) fraction was determined by fire assay followed by ICP-atomic fluorescence spectroscopy. All precious metals were analyzed by Chemex Labs Ltd.

The carbonate content of the silt plus clay (<0.063 mm) and fine sand (0.125–0.250 mm) fractions was determined using a Leco carbon analyzer to measure carbon concentrations, which were converted to per cent CaCO_3 equivalent using a modification of the method of Foscolos and Barefoot (1970). Carbonate determinations on the silt plus clay (<0.063 mm) fraction of around 20 samples were performed by the Chittick method (Dreimanis, 1962). Raw data from Leco and Chittick analyses are accurate only to within 1–2% and analytical errors may be further compounded as number values are rounded during calculation of the CaCO_3 equivalent. Grain size analyses of the 2 mm to 0.044 mm fraction were performed with sieves and, for sediment <0.044 mm, the pipette.

In this, as in earlier studies, emphasis was placed on the fine fractions of the matrices of glacial sediments. Experiments undertaken to study chemical partitioning show that there is a disproportionate amount of base metals in clay-sized as opposed to coarser parts of the till matrix (Shilts, 1975, 1984b) and that the finer fractions of till are more auriferous (DiLabio, 1988). The clay-sized fraction is composed predominantly of phyllosilicates, and also finely divided Fe-Mn oxides/hydroxides, and organic matter (Shilts, 1984b). In addition to metal held in their structure, phyllosilicates may be enriched in adsorbed secondary metals, released from labile minerals, such as the sulphides, during weathering. The clay-sized fraction was not analyzed

for precious metals as the weight of sample required for reliable analyses is so large that it is impractical to carry out routine clay extractions for this purpose.

The greatest concentration of carbonate minerals is in the silt-sized portion of the till matrix (Dreimanis and Vagners, 1971). As with precious metal analyses, the carbonate content of the combined silt-clay fraction was determined as it is virtually impossible to separate all clay from silt-clay mixtures (Jackson, 1956).

Selected Precambrian and Paleozoic lithologies were separated from the granule-small pebble fraction (2–5.6 mm) of 112 samples collected in 1980 and 1981 and of 251 samples collected after 1986. The weight per cent of each lithologic group in 20–40 g of the total fraction was calculated.

Results of analyses, with sample locations and descriptions for samples collected during this and the earlier study, were stored on computer files. Geochemical and pebble lithology data for a representative sample from each site were plotted using a computer program, Lazerdot, developed by Wyatt Geoscience, Ottawa.

For selected silty clay samples, the residue greater than 0.18 mm, extracted from 200 g of sediment, was examined for microfossils by Cyril Rodrigues, University of Windsor.

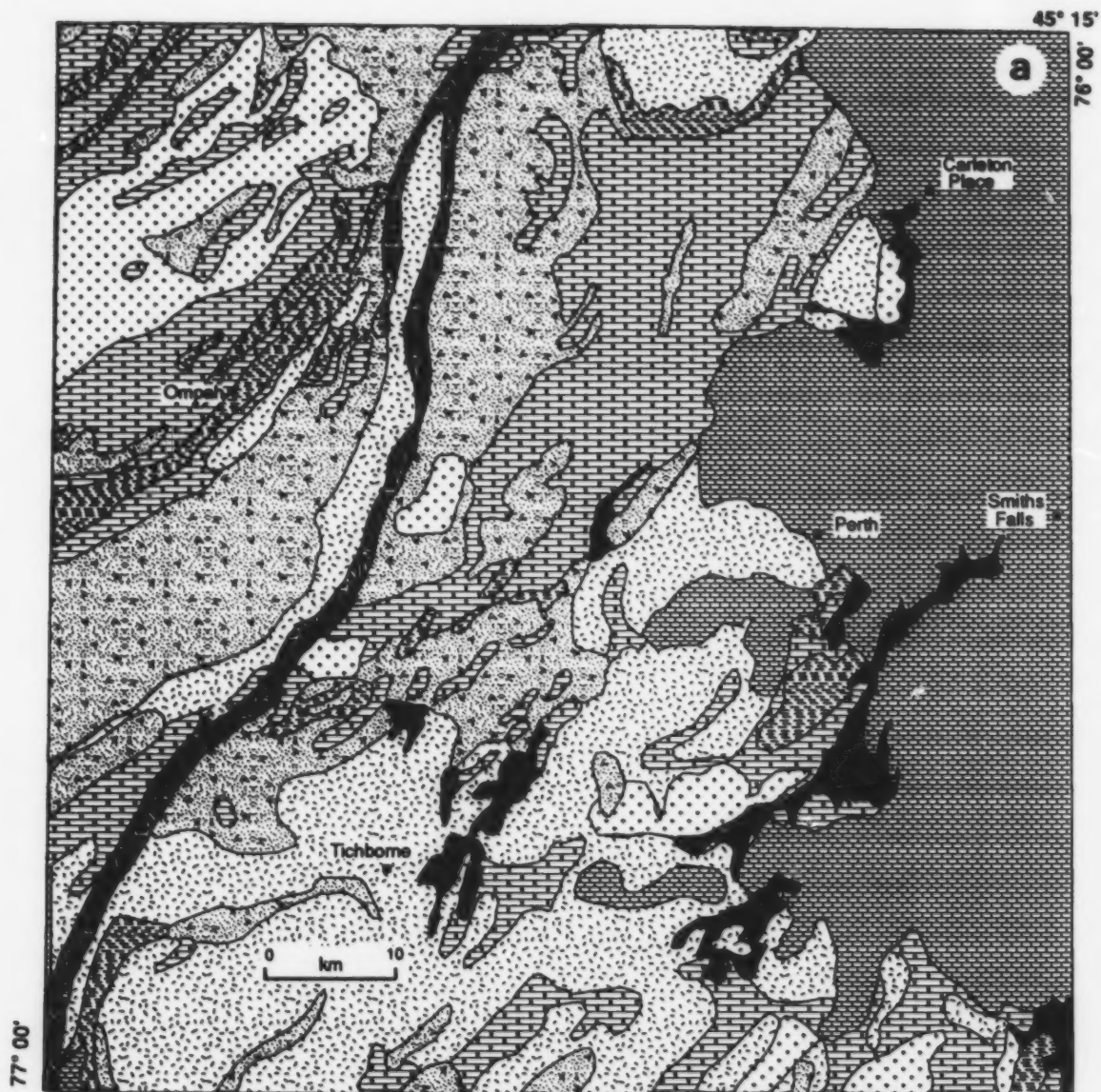
BEDROCK GEOLOGY

Regional bedrock mapping in the study area and surrounding areas was compiled at a scale of 1:1 000 000 by Baer et al. (1971) and Sanford and Baer (1971), and at 1:800 000 by Freeman (1979). The following maps are available at a scale of 1:50 000 or less for the map areas shown in Figure 1:

- (1) Clyde Forks (31F/02) — Easton (1987, 1988, 1990), Pauk (1984a), Lumbers (1982), Karboski (1980), Rivers (1976), and Gleeson et al. (1989).
- (2) Sharbot Lake (31C/15) — Smith (1958), Pauk (1982, 1984b, 1987), Wolff (1982a, b, 1985), Harding (1942, 1947), Hewitt (1964), and Easton and MacMaster (1987).
- (3) Perth (31C/16) — Wilson and Dugas (1961).
- (4) Westport (31C/09) — Wynne-Edwards (1967).
- (5) Carleton Place (31F/01) — Reinhardt (1973).
- (6) Tichborne (31C/10) — Wolff (1982a, b).

A summary of the bedrock geology, much of it based on the work of Easton (1987, 1988), is presented below and in Figure 5a.

There are two main types of bedrock terrane in the study region (Baer et al., 1971). To the east are flat-lying, unmetamorphosed Ordovician limestone, dolostone, shale, and sandstone. The remaining area is underlain by middle to late Proterozoic rocks of the Central Metasedimentary



44° 30'

Paleozoic



limestones, dolostones,
sandstones, shales

Precambrian



Robertson Lake
Mylonite Zone



marbles



non-carbonate
metasedimentary
bedrock



mafic intrusive and
mafic metavolcanic bedrock



medium to high grade
gneissic bedrock



felsic intrusive and felsic
metavolcanic bedrock

Figure 5. (a) Bedrock geology of the Clyde Forks-Westport area, modified after Easton (1987) Easton and MacMaster (1987), Baer et al., (1971), and Freeman (1979); (b) metamorphic terranes of the Clyde Forks-Westport areas, modified after Moore (1982). (RLMZ — Robertson Lake Mylonite Zone, LGC — Lavant Gabbro Complex, SLT — Sharbot Lake Terrane)



Belt of the Grenville Province. These are characterized by massive outcrops and sharp but low relief. Included in the Central Metasedimentary Belt are two prominent structural features — the Frontenac Axis to the southeast and the Mount St. Patrick Escarpment which marks the northern edge of the Madawaska Highlands (Fig. 2).

Three metamorphic terranes within the Central Metasedimentary Belt have been recognized (Moore, 1982; Fig. 5b). The Sharbot Lake Terrane, in the east, is separated from the Elzevir Terrane, to the west, by the Robertson Lake Mylonite Zone. The Sharbot Lake Terrane is characterized by a series of mafic flows and pyroclastic rocks, minor pyritiferous metasedimentary rocks, and marbles, all intruded by gabbro, diorite, and tonalite of the Lavant Igneous Complex. These units are generally metamorphosed to the lower amphibolite facies. The Elzevir Terrane consists of a series of mafic to felsic volcanic strata, metasedimentary clastic rocks (some of volcanic origin), and marbles metamorphosed to middle and upper amphibolite facies. Between Ompah and Clyde Forks, distinctive clastic metasedimentary rocks outcrop, many of which are muscovite-bearing. The Robertson Lake Mylonite Zone, a major shear zone, includes highly sheared and fractured gabbro, metavolcanic, clastic metasedimentary and carbonate units. The rocks are strongly carbonatized, and chloritized, and in places, pyritization, silicification, and sericitization are common.

The Frontenac Terrane, which encompasses the Perth-Westport area, consists of upper amphibolite to granulite facies migmatites and gabbroic-anorthositic intrusions with minor marble, clastic metasedimentary rocks and granites. These units are separated from rocks of the adjacent Sharbot Lake Terrane by a deformation zone.

According to Sangster (1982), Carter et al. (1980), and Gleeson et al. (1989), the following types of mineral deposit are present in the study area:

- (1) carbonate-hosted Pb and Zn deposits.
- (2) carbonate-hosted Cu-Sb-Au-Ag and Cu-Sb-Au-Hg deposits and volcanic-hosted Cu-Zn deposits.
- (3) gabbro-hosted Cu-Ni deposits.
- (4) gabbro-hosted Au in quartz-ferroan dolomite veins.
- (5) altered trondhjemite-hosted Au in quartz veins.
- (6) mafic mylonite-hosted Au in massive sulphide zones.
- (7) carbonate skarn- and volcanic-hosted Fe in magnetite deposits.
- (8) carbonate-hosted Fe in fault related hematite deposits.
- (9) pyrite deposits with no consistent geological association.
- (10) skarn-, pegmatite- and paragneiss-hosted Mo deposits.

Mineral occurrences in the study region are shown in Figure 6 and Table 1. An important past producer is the Pb-Zn mine at Long Lake in the Tichborne map area.

SURFICIAL MATERIALS AND LANDFORMS

Descriptions of the Quaternary deposits shown on the surficial geology maps for the Clyde Forks-Westport area (maps 1798A-1801A) are presented below and summarized in Table 2.

Rock (R and R)

Exposed rock and rock covered with very thin (<0.25 m) drift are designated as bedrock on the surficial geology maps (maps 1798A-1801A). Throughout the study area, bedrock is commonly exposed, and bedrock structure strongly controls topography. Drift cover is especially scanty in the Sharbot Lake, northwestern Clyde Forks, and south-central Perth map areas.

Bedrock outcrops are generally rounded and may be striated, grooved, or bear crescentic markings. Except for the upper few millimetres to few centimetres of the outcrop surface, postglacial weathering of bedrock is generally negligible. In the marble belts northeast of Clyde Forks, karst features such as sink holes and channels were observed in places, but no age can be assigned to them.

Striae are most commonly preserved on fine grained, flat-lying, Paleozoic sedimentary rock (R). The hard, coarse grained, mineralogically diverse Precambrian crystalline rock (R) was likely less easily striated by overriding ice and, where present, striae and shallow grooves are less well preserved as the upper few millimetres of the rock surface weathers irregularly.

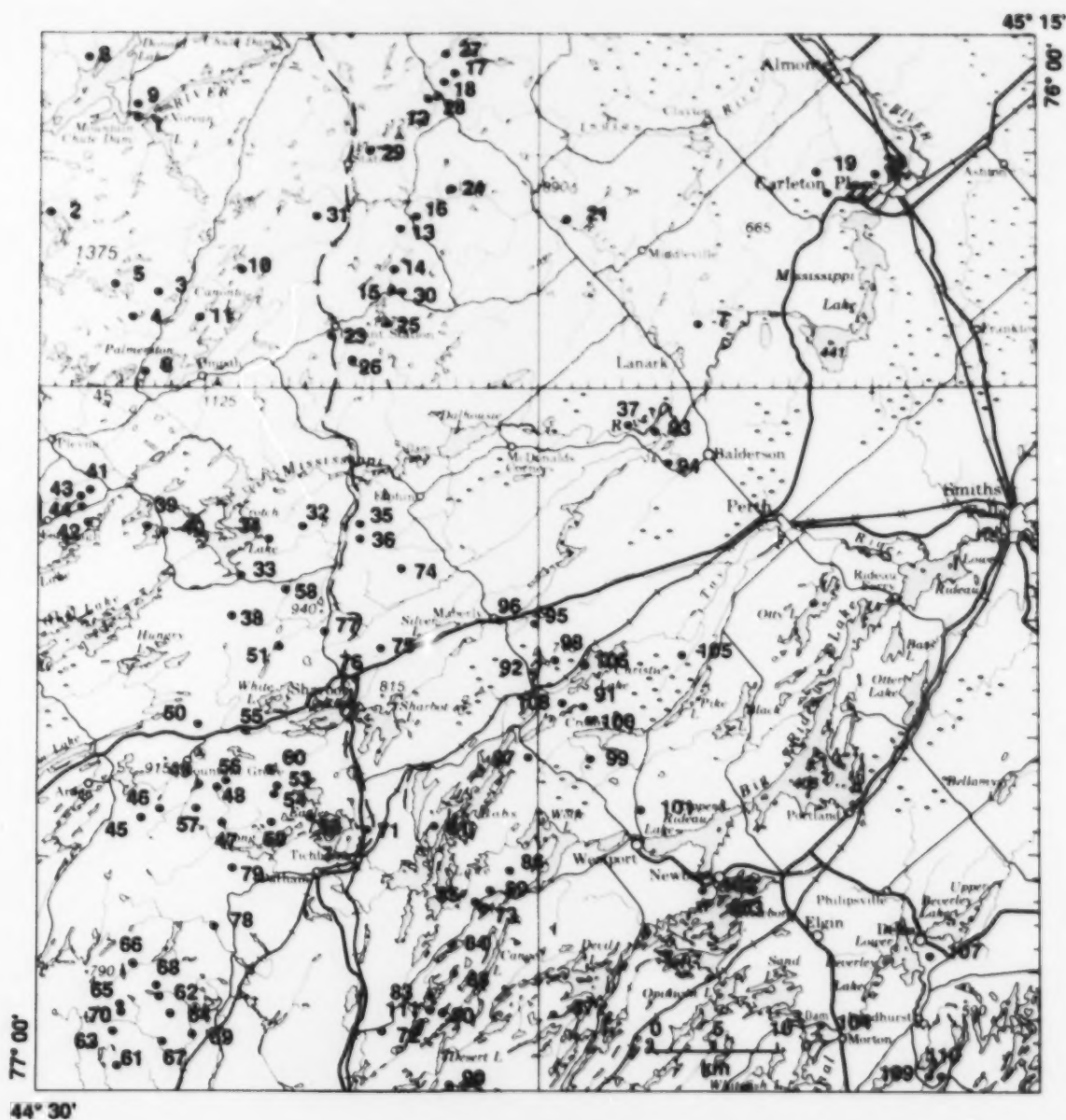


Figure 6. Mineral occurrences in the Clyde Forks-Westport area. Deposits are numbered and explained in Table 1.

Bow-shaped furrows and related features termed *sichelwannen* (Allen, 1984) were very occasionally noted on bedrock. Whether these features formed due to differential abrasion by debris-laden ice (Boulton, 1974) or by erosion by subglacial meltwater flows (Shaw, 1988) is still debated. Some of the best developed ones were observed underlying the subaqueous fan deposits near Morton (Henderson, 1988) and on the shore of Charleston Lake (Fig. 7a). A well developed series of solution pits or potholes approximately 0.5 m in diameter was also observed on the shore of Charleston Lake (Fig. 7b).

Glacial and proglacial deposits

Till (1a and 1b)

The most widespread surface deposits are diamictons which are postulated to be deposited either directly from, or in close association with, glacial ice, and to have physical and chemical characteristics that closely approximate those of the debris load carried by the last glacier to cross the project area. For the purposes of the study, these diamictons are referred to collectively as till. Little attention was given to accurate identification of till facies due to the shallow

Table 1. Mineral occurrences in the Clyde Forks-Westport region. Numbers correspond to those of Figure 6 to show deposit locations.

Number	Deposit Name	Commodity	Number	Deposit Name	Commodity
1	Mountain Chute	U, Th	56	McKnight, Wm.	Au, Ni
2	Barnet, T.F.	U, Th	57	Smith	Zn
3	Kellar	U, Th	58	Guardian	U
4	Bordon	U, Th	*59	Long Lake	Zn, Ag, Pb
5	Honsberger, J.C.	U, Th	60	Sharbot Lake	Cu, Cu, Ni
6	Mosque Lake	Cu, Pb, Zn	61	Sheffield	Fe
7	Pine Grove Mica	Ag, Au	62	Lennox Mines	Zn, Cu, Pb
8	Matawatschan Road	Mn, Sr, V	63	Calvert	Mo
9	Box, J.S.	Mo	64	Spratt, Matthew	Mo
10	Longstone Lake	Fe	65	Kellar	Mo
11	Summit Lake	Fe	66	Wager	Mo
12	Green Lake	Au, Cu, Sb, Ag, Bi, Hg, Pb, Zn	*67	Chisholm, A.M.	Mo, Au, Ni
13	Lavant Creek	Cu, Ag, Au, Bi, Hg, Pb, Sb, Zn	68	Slave Lake	Mo
14	Nelson Lakes	Cu, Ag, Au, Bi, Hg, Sb, Zn	69	Burns	Mo
15	Lynx-Canada	Cu, Ag, Au, Pb, Sb, Zn	70	Oberkerk	Mo
16	Lavant	Ag, Au, Cu, Sb, As, Bi, Hg, Zn	*71	Eagle Lake	Fe
17	Bradford's Creek	Au, Cu, Sb, Ag, Zn	72	Campaill, Ernie	Fe
18	Darling	Au, Cu, Sb, Ag, Bi, Hg, Pb, Zn	73	Brennan, John	Pb, Zn
19	Lynch	Pb	74	Tysick, Duncan	Au
20	Ramsay Lead	Pb, Ag, Cu, Zn	75	Mcveigh, R.	Au
21	Pharoah, H.	Zn, Ag, Pb	76	Morrow, Andrew	Au
22	Ramsay	Ag, Au, Pb	77	Bourk, R.T.	Au, Cu
23	Twenty Six Lake	Fe	78	Drader, Mrs. H.	Mo
24	Lavant	Fe	79	Concession 1, Lot 3	Mo
25	Robertson, H.S.	Au	80	Desert Lake	Fe
*26	Wilbur	Fe	81	Crow Bay	Fe
*27	Yuill	Fe	*82	Howse	Fe
28	Darling	Fe	*83	Glendower	Fe
*29	Radenhurst and Caldwell	Fe	84	Murphy, Leo	Pb
30	Begin, J.	Cu, Ag, Au	85	Murphy-Hickey	Pb, Cu, Zn
31	Clyde Forks	Ag, Cu, Hg, Sb, As, Bi, Sn	86	Patterson	Pb
*32	Canorex	U, Th	87	Moore, G.W.	Fe, Cu, Ni
33	Rexdale	U, Th	*88	Black Lake	Fe
34	Westwind	U, Th	89	Robinson	Pb, Zn
35	Robertsville	Fe	*90	Grainger, Frank	Sr
36	Picamine	Cu	*91	Fournier	Fe
*37	Playfair	Fe	92	Orner-Kraft	Th, U, Nb, Re
38	Alit-El	U, Th	93	Bayne Farm	Fe
39	Consolidated Golden	U	94	Innes, C.	Nb, Th, U
40	Fyock M H and Assoc	U	95	Ritchie	Fe
41	Boerth	Au	96	Morran	Fe
42	Cook	Au, As	97	Bygrove	Fe
43	Webber	Au	98	Silver Lake	Fe
44	Clarendon	Pb, Ag	99	Strong, W.H.	Fe
45	Hughes, Amos	Cu, Pb, Zn	100	Allan	Fe
46	Big Clear Lake	Cu, Ni	101	Merkley, Samuel	Mo
47	Hawley	Zn, Cu, Pb	*102	Matthews	Fe, Ti
48	Lynx	Zn	103	Chaffey	Fe, Ti
49	Carnahan Lake	Cu, Ni	104	Jones Falls	Fe
50	Gray, Percy	Mo	105	Bellew, H.C.	Sr
51	Avery	Mo	106	Christie Lake	U, Fe, Nb, Re, Th
52	Varete	Mo	*107	Delta	Fe
53	Macdonnell, G.M.	Mo	108	South Sherbrooke Tp.	Au, Ag
54	Smith, Ed	Au	109	Singleton	Sr
55	Bertrim	Au	110	Long Point	Pb
			111	Thirty Island Lake	Zn

*past producer

depth of most exposures available for systematic study at a reconnaissance scale. Stratigraphically, only one unit of till has been recognized. On the basis of Terasmae's (1965) correlation of the upper till unit in the Cornwall area with the Fort Covington Till in New York state (MacClintock and Stewart, 1965), Sharpe (1979) referred to the till in the nearby Merrickville area as Fort Covington Till.

The till is grey when unoxidized and tends to be stony and sandy in texture due to the coarsely crystalline nature of the Precambrian source rocks (Fig. 8). The average texture of the <2 mm fraction of 665 samples classified as

till is 68% sand (2-0.063 mm), 25% silt (0.063-0.004 mm), and 7% clay (<0.004 mm) with the 5th and 95th percentile for each class being 48% and 85%, 12% and 40%, and 2% and 17%, respectively. Rare occurrences, most in the Westport area, of red clayey till bearing rounded granite pebbles, were also noted. These were usually found outcropping along the sheltered part of a bedrock knob or ridge and are thought to be derived from isolated remnants of the Precambrian-Paleozoic paleosol.

Table 2. Summary descriptions of Quaternary deposits and bedrock lithologies in the Clyde Forks-Westport area.

QUATERNARY

POSTGLACIAL DEPOSITS

7 ORGANIC DEPOSITS: mainly muck and peat; 1 to 5 m thick; occurs in bogs, fens, swamps and poorly drained areas.

6 ALLUVIAL DEPOSITS: silt, sand, and gravel with minor organic material; 1 to 5 m thick; modern floodplain or deltaic deposits; surfaces commonly scarred by abandoned channels.

PROGLACIAL AND GLACIAL DEPOSITS

MARINE DEPOSITS: stratified to massive, clay to gravel deposited in deltaic, littoral, estuarine, nearshore, and deep water environments of the Champlain Sea; rarely fossiliferous; in many places underlain by glaciolacustrine sediments.

5b Littoral and nearshore sediments: gravel, gravelly sand, sand, minor silt, generally well sorted; 1 to 25 m thick; occurs as beaches, bars or sheets; includes deltaic and estuarine deposits.

5a Offshore sediments: silt, silty clay, and clay, locally overlain by thin sand; 1 to 10 m thick.

GLACIOLACUSTRINE DEPOSITS: stratified to massive, clay to gravel deposited in deltaic, littoral, nearshore, and deep water environments of glacial lakes.

4b Littoral and nearshore sediments: gravel, gravelly sand, sand, minor clay, generally well-sorted; 1 to 25 m thick; includes nearshore and deltaic deposits; generally occurs as fills in topographic depressions.

4a Offshore sediments: silt, silty clay, clay, minor sand; 1 to 10 m thick; laminated to massive.

GLACIOFLUVIAL DEPOSITS: stratified sediments deposited at or near the glacier margin by meltwater streams.

3 Proglacial sediments: gravel, gravelly sand, and sand; 1 to 10 m thick; includes outwash; occurs as terrace remnants that are generally graded to former glacial lake or sea levels.

2 Ice contact sediments: boulder and/or cobble gravel, gravelly sand, sand, minor silt, and diamict; 5 to 30 m thick; includes ice marginal subaqueous fan, esker, and delta deposits.

GLACIAL DEPOSITS: sandy or occasionally silty diamict; minor lenses or stringers of sand or silt; deposited directly by the glacier as till.

1b Till veneer: discontinuous cover over rock; average thickness less than 1 m on interfluvies, thickens locally in small depressions and on the lee sides of bedrock knobs; may include discontinuous, thin (< 1 m) pockets of sand and gravel or silty clay in low lying areas.

1a Till blanket: generally continuous cover which masks bedrock morphology, few outcrops; greater than 1 m thick on interfluvies; where streamlined, thickness commonly exceeds 2 m; small deposits of stratified sand, gravel, and boulders frequently occur on the down-ice end of streamlined features.

PRE-QUATERNARY

BEDROCK: rock, locally with a thin (< 0.5) and discontinuous cover of surficial sediments.

R Paleozoic rock, unsubdivided; includes limestone, dolomite, sandstone, and locally shale; relatively flat-lying, occurring as bare tabular outcrops.

R Precambrian rock, unsubdivided; medium- to high-grade gneiss, carbonate metasediments, metavolcanics, felsic intrusives, mafic intrusives, and noncalcareous metasediments; structurally complex; mainly forming rolling or hilly rock knob uplands.

The till is generally not very compact and either lacks cohesion or fractures in small (<1 cm) angular peds, composed of sand and granules with a cohesive silt-clay matrix. In the rare deeper exposures examined, till of similar texture can be fairly compact, but the origin of its compactness cannot be ascribed confidently to its mode of

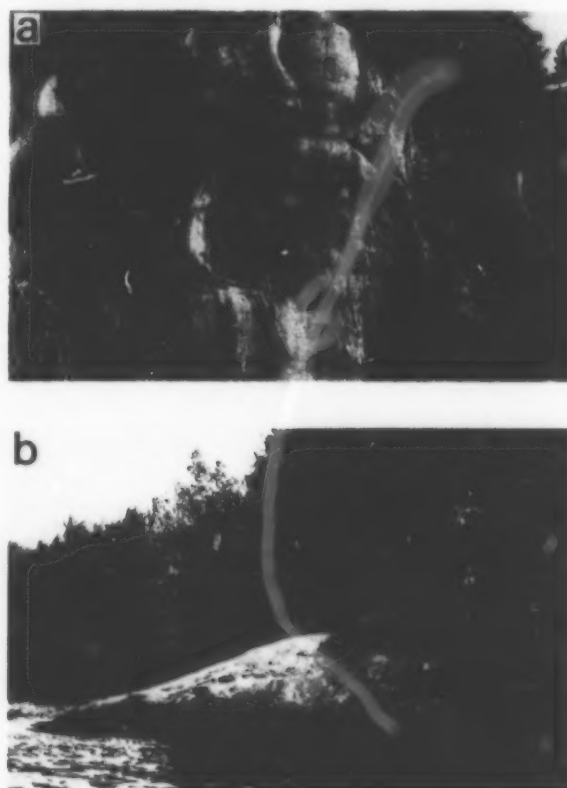


Figure 7. (a) Sichelwannen and (b) solution pits or potholes on bedrock shore of Charleston Lake. GSC 205248; GSC 205252

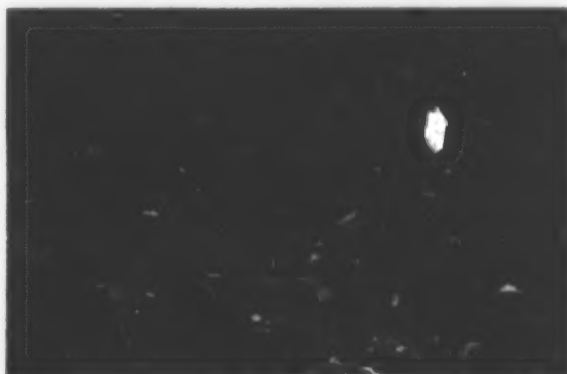


Figure 8. Till enriched in marble boulders and clasts, Sharbot Lake area. GSC 205247

deposition. Increased compaction with depth may simply reflect the load of the overlying sediment combined with desiccation on being exposed to the air.

Where good exposures exist, till commonly contains stringers or clasts of water-sorted sediment or interbeds of water-laid sediments, which suggests that it was emplaced by meltout. After detailed study of glacial sediment facies in similar Shield terrain farther west in the Haliburton area, Kaszycki (1988) concluded that most till was deposited by basal meltout. Debris was released from ice which stagnated subglacially as the ice sheet thinned and slow moving basal ice became entrapped within enclosed bedrock basins.

Over most of the study area, till deposits take the form of a thin, featureless, discontinuous veneer (0-1.5 m thick) which fails to mask the structure of the underlying bedrock (Fig. 9). Locally, deposits may be thicker (1.5-5 m) in depressions, along valley walls, and on both the up-ice and down-ice sides of bedrock ridges. On a regional scale, thicker deposits commonly take the form of drumlins. Till is also thicker, though still discontinuous and, for the most part, featureless over an area north of Perth (D on Fig. 10), and in at least three discontinuous belts which trend approximately east to east-southeast (A, B, and C on Fig. 10).

Figure 11 shows the distribution of drumlins in the project area and surrounding regions. Drumlin orientation changes from south-southwesterly on the southwest side of the Mount St. Patrick escarpment and over the southern half of the study region, to southerly on the east side of the escarpment, to southeasterly on the north side of the escarpment and in the Ottawa River Valley. In rugged Precambrian terrain in the Clyde Forks and Carleton Place map areas, drumlins occur for the most part in longitudinal belts oriented parallel to ice flow which make crudely concentric, arcuate bands. Spacing between the longitudinal belts increases westward. Within the belts, drumlins are commonly 2-3 km in length, are spaced 2-3 km apart, and normally occur on high ground or at the edges of small plateaus. Exposures within the drumlins revealed till that is noticeably finer grained than the generally thin till found between drumlins.



Figure 9. Terrain with a discontinuous cover of thin till, Sharbot Lake area. GSC 205246

In contrast, over flatter Paleozoic terrain, drumlins are clustered in fields north and south of Smiths Falls and, outside the study area, south of Ottawa (Fig. 11). Within these fields, drumlins are smaller and more closely spaced, particularly within the field south of Ottawa. Excavations on drumlins almost always expose till, though crudely stratified bouldery gravels were exposed in a borrow pit excavated in the down-ice end of one large drumlin northwest of Smiths Falls. Again in the Smiths Falls region, drift cover between drumlins is thin.

North of Perth, thicker till overlies Paleozoic sandstone and dolomite which have an outcrop area that takes the form of an embayment surrounded by more rugged Precambrian bedrock on the north, west, and south sides (D on Fig. 10). Here, increased drift thickness likely reflects the interplay of the configuration of Paleozoic and Precambrian outcrop areas and the low resistance of the Paleozoic lithologies to glacial erosion relative to the nearby Precambrian lithologies. After crossing the shield terrane immediately to the north, the debris load of the overriding glacier would have been composed, in part, of massive, hard, coarsely crystalline erratics well suited for grinding the underlying Paleozoic bedrock. The author has observed similar thickening of the till cover on, and immediately down-ice of, Paleozoic outliers on the Canadian Shield near Queensborough, west of the study region.

The most southerly of the three east- to east-southeast-trending belts of thick till (A on Fig. 10) lies in the southwestern corner of the study region and forms part of the Dummer Moraine. The two more northerly belts (B and C on Fig. 10) cross the study area south of Perth and south of Westport. The northernmost belt (C on Fig. 10) can be traced eastward across the Merrickville area (see Ontario Geological Survey Map 2387, Sharpe, 1979) which lies immediately east of the study region.

The two northerly belts (B and C) are interpreted as weakly developed recessional moraines. They are parallel to nearly parallel to the more prominent Dummer Moraine (A on Fig. 10; Fig. 2). They are also nearly perpendicular to the prominent networks of subaqueous outwash deposits described in more detail below, and to the predominant direction of regional ice flow as determined from glacial striae.

Glaciofluvial deposits

Ice contact sediments (2)

Glaciofluvial ice-contact deposits are widely distributed and commonly take the form of small isolated kames, kame terraces, or leeside deposits (Hillefors, 1973). Glaciofluvial deposits are composed of complexly bedded and faulted, coarse bouldery to cobbly gravel and diamicton interbedded with sand, gravel, and in some places, rhythmically bedded fine sand and silt.

Many leeside deposits (usually too small to be mapped) were noted in the southern Clyde Forks map area. Where kame terraces are present they are found perched on, or

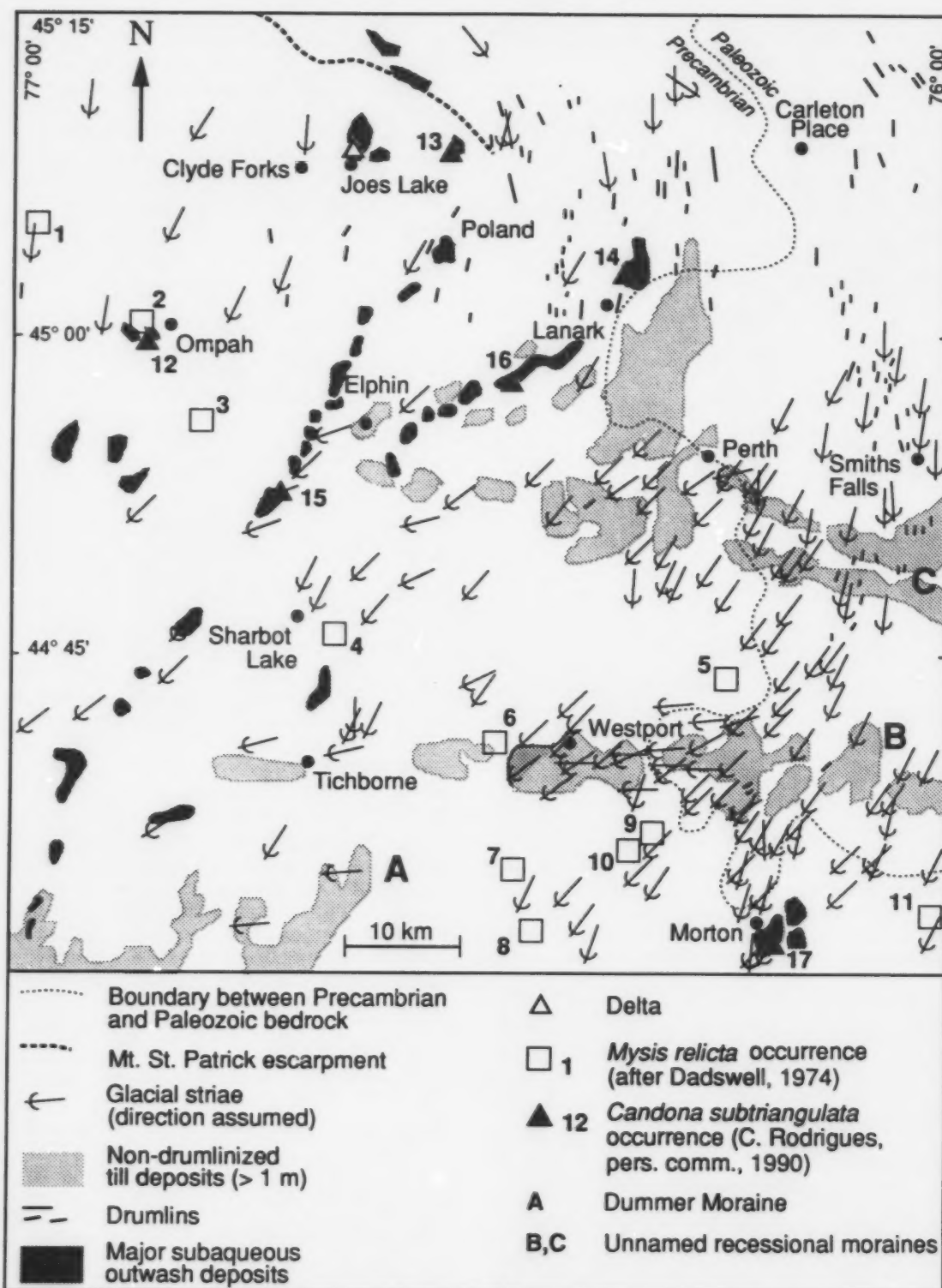


Figure 10. Selected surficial deposits and ice flow direction indicators in the Clyde Forks-Westport area as determined by Kettles (this study), Henderson and Kettles (map 1799A, in pocket), Richard (1990) and Henderson (1973). Occurrences of *Candona subtriangulata* (C. Rodrigues, pers. comm., 1990) and *Mysis relicta* (Dadswell, 1974) are also shown.

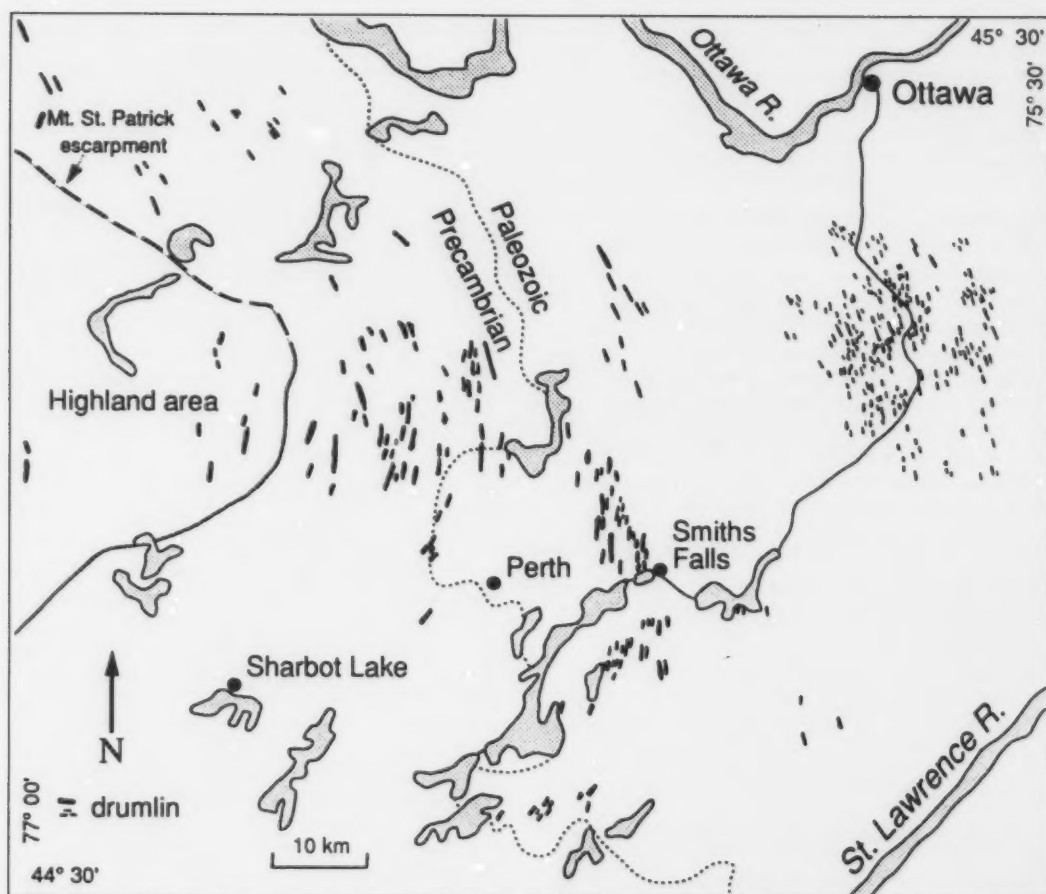


Figure 11. Distribution of drumlins in the Clyde Forks-Westport-Ottawa area. Highland area on west margin has elevation greater than 350 m a.s.l.

flanking valley sides, but terracing is in most places indistinct. Well developed kame terraces were noted immediately north of Westport.

Most prominent are the networks of subaqueous outwash fan deposits similar to those described elsewhere by Rust and Romanelli (1975), Banerjee and McDonald (1975), and Kaszycki and DiLabio (1986) and within the study area by Gorrell (1986) and Henderson (1988). These deposits are composed of an esker core of glaciofluvial cobbly, bouldery gravel thought to have been deposited subglacially at or near the ice margin as water in subglacial meltwater channels debouched into a proglacial lake. The coarse core is overlain by a sequence of bedded sand and gravel which are, in turn, commonly capped by laminated silt and clay. The textures and primary sedimentary structures characteristic of the different facies commonly associated with these deposits are shown in Table 3 (after Henderson, 1988, Table 1).

Subaqueous fan deposits occur as roughly linear discontinuous sediment accumulations localized in bedrock-controlled valleys oriented approximately parallel to ice-

flow direction. They commonly form broad ridges which may exhibit a sharp crest in some places. Deposits associated with three well developed systems lie within the study region (Fig. 10). The first of two long networks extends from southeast of Elphin (includes site 16, Fig. 10) to a very large deposit in the Lanark area (site 14, Fig. 10; Fig. 12), while the second extends northeastward from Tamworth to the Poland area (includes site 15, Fig. 10). Another large but isolated complex (site 17, Fig. 10), mentioned above, is near Charleston Lake in the Westport map area (Henderson, 1988).

Proglacial outwash deposits (3)

The large delta at Joes Lake (Fig. 10) in the Clyde Forks map area is the only deposit in the study area mapped as a proglacial subaerial outwash. This delta was built before the ice margin had receded from McCreas Hill, 3 km to the north, as the hill would have otherwise acted as a topographic barrier to continued water flow from the ice front to the delta. The exact position of the ice margin as the delta was forming, is however, uncertain and it is possible that the delta is an ice contact deposit. The cobbly, bouldery

Table 3. Subaqueous outwash fan facies after Henderson (1988).

Facies	Grain size and structures	Interpretation
Clast-supported gravel	Cobbles and boulders; well rounded; well sorted with minor matrix; long axes oriented parallel or transverse to flow	Proximal facies deposited within glacial tunnel or confined ice-marginal conduits
Stratified gravel and coarse sand	Pebbles, granules, coarse sand; stratified; series of graded to inverse-graded beds; steeply dipping	Ice-proximal facies deposited as subaqueous grain flows in response to sporadic and variable current
Planar cross-bedded sand	Sand, coarse to fine grained; few angular pebbles; intermittent thin, laterally continuous silt-clay beds between groups of cosets	Interchannel facies (mid-fan) deposited as avalanche of bedload sediment down lee side of migrating sand waves in intermittent periods of low to zero current flow
Ripple-drift cross-stratified sand	Sand, medium to fine grained; all ripple types, minor parallel sand lamination, and planar cross-bedded sand; intermittent thin, laterally continuous silt-clay beds; few angular pebbles (dropstones)	Interchannel facies (lower fan) of rhythmic sedimentation deposited in response to fluctuations in meltwater flow
Stratified fine sand, silt, and clay (rhythmites)	Sand, silt, clay; fining-upward rhythmic sequence; sand bed may be massive, graded, or rippled, minor ball and pillow structure, rip-up clasts; occasional angular pebbles (dropstones)	Distal facies, proglacial lacustrine; sediments occur as channel fill and in downwarped areas; deposition is from sediment gravity flows
Massive sand	Sand, coarse; structureless; contains rip-up clasts	Channel fill, mass-flow deposit

a

Figure 12. Exposures in long discontinuous network of subaqueous outwash deposits located east of McDonalds Corners; (a) Planar crossbedded sand (mid-fan) facies exposed on height of land in Poole's gravel pit; (b) Laminated silty clay sediments capping stratified, faulted sands and gravels in Cavanagh's gravel pit. GSC 205251; GSC 205249

texture of some foreset beds exposed at Joes Lake and the presence of a well developed kettle hole on the delta surface indicate that these sediments were deposited close to ice. It is also possible that some sediments mapped as ice contact glacial deposits in the channel north of and leading to the delta, were deposited as proglacial outwash.

Glaciolacustrine deposits (4a and 4b)

Two types of glaciolacustrine deposit were distinguished in the study area: offshore (4a), and nearshore to littoral (4b). Rhythmically bedded to massive silty clay and fine sand identified as offshore sediments (4a) are widely distributed in low-lying areas dominated by flat-lying Paleozoic terrain, south and east of Westport and in the vicinity of Perth, well outside projected limits of marine incursion (Henderson, 1973). Elsewhere in the study region, nearshore to littoral sediments (4b) are common in low lying areas and are generally composed of the interbedded gravels and sands characteristic of the mid, lower, and distal facies of subaqueous outwash fan deposits (Table 3; Henderson, 1988).

Beaches are not well developed on this part of the Canadian Shield, and, where present, are not easily recognizable as the terrain is rugged and heavily forested.

Sediment supply was generally scanty as evidenced by the thin blanket of drift (usually <1 m) which covers the region. In most areas, the retreating ice margin formed a significant part of the proglacial lake shore. Where proglacial lakes flooded Precambrian terrain, wave energy was dissipated by the presence of rocky islands and the irregular outline of the rocky shoreline.

Marine deposits (5a and 5b)

Some of the deposits of rhythmically bedded clay, silty clay, silt, fine sand, and stratified sands and gravels identified as offshore (5a) or nearshore to littoral sediments (5b) found in the Perth-Smiths Falls area may be of marine origin (Henderson, 1973). The Champlain Sea extended west of Perth at its western maximum limit of incursion. Henderson (1973) noted non-fossiliferous, brown, sticky clays that are atypical of the glaciolacustrine facies in the Smiths Falls area.

Unfossiliferous beaches and bars (5b) have been identified on relatively flat-lying Paleozoic terrane north and west of Smiths Falls, within the area thought to have been covered by the Champlain Sea.

Postglacial deposits

Alluvium (6)

Since deglaciation there has only been minor erosion and redeposition of unconsolidated sediment on modern stream valley floors or lacustrine deltas. Deposits are composed of silt, sand, and gravel with minor organic material. The best-developed alluvial deposits are seen north and west of Lower Beverly Lake in the Westport map area, where surfaces are scarred by abandoned channels.

It is possible that areas of alluvial deposits are under-represented on the Quaternary maps accompanying this report. In Precambrian terrane, it is commonly difficult to distinguish, by either field observations or air photo interpretation, surface sediment types in the poorly drained areas adjacent to modern streams. In some poorly drained areas, alluvial silts, sands, and gravels, rather than muck or peat (unit 7), may predominate.

Organic deposits (7)

There has been widespread formation of organic deposits over the study region since deglaciation. These deposits, composed of muck and minor peat, range in area from a few tens of square metres to the approximately 40 km² Blueberry Marsh located north of Perth. In many places, areas covered with organic deposits are contiguous with present day streams or lakes. Most organic deposits likely formed when the patterns of fluvial drainage were disrupted by tilting due to isostatic rebound. They also formed when stranded ice blocks melted leaving undrained depressions, many of which tend to be round in shape, or when surface drainage patterns were altered by beaver activity.

LATE WISCONSINAN GLACIAL HISTORY

Ice flow history

All glacial deposits in this area are considered to be Late Wisconsinan (Fulton et al., 1986). The last ice to occupy the area may have been the same sector of the Laurentide Ice Sheet that extended to the Late Wisconsinan terminal

moraine in New Jersey (Fulton et al., 1986). By approximately 12.5 ka deglaciation was occurring in central and eastern Ontario (Anderson and Lewis, 1985). One lobe of ice which receded from the Ontario basin into the Upper St. Lawrence valley, may be distinguished from ice in the area north of the Ontario basin (Prest, 1970; Anderson and Lewis, 1985).

During the Late Wisconsinan the predominant ice flow direction was south-southwestward in the Clyde Forks, Perth, and Westport areas, but was more westerly in the Sharbot Lake and Tichborne areas (Fig. 10). During the last stages of glaciation ice flow patterns appear to have been strongly controlled in some places by topography. There was, locally, westerly flow along two east-trending valleys, the Tay River Valley south of Perth and the broad valley south of Westport (see also Henderson, 1973; Gadd, 1980), also in low lying areas southwest of Bobs Lake in the Tichborne map area. In the northern part of the study region, ice flow patterns were likely controlled by the Mount St. Patrick escarpment which has a local relief of over 125 m in places. Striae orientation changes from south-southwesterly on the southwest side of the escarpment, to southerly on the east side of the escarpment, and southeasterly both on the north side of the escarpment and in the Ottawa River Valley (Fig. 10, 11). In the Ottawa Valley, older southwestward- and younger southeastward-trending striae are both present (Gadd, 1980, Fig. 1).

The presence of the Dummer Moraine and the proposed minor recessional moraines south of Westport and Perth (Fig. 10), suggests that the ice margin was oriented approximately east to east-southeast as the glacier retreated northward at least as far north as Perth. This view of ice retreat in the study region is more consistent with the one presented for this part of southeastern Ontario by Chapman and Putnam (1966) and Prest (1970) than the one presented later by Gadd (1980) where the retreating ice mass had a lobate margin.

Glaciolacustrine/lacustrine events

By approximately 12.5 ka, glacial Lake Iroquois was flooding the southern end of the Ontario basin (Anderson and Lewis, 1985) and expanding against the ice margin as the glacier retreated. Lake Iroquois drained eastward through an outlet 150 km southeast of Kingston at Rome, New York. Later, several lower lake phases came into existence when ice receded up the upper St. Lawrence Valley, uncovering lower outlets approximately 225 km northeast of Kingston near Covey Hill, Quebec (Prest, 1970; Clark and Karrow, 1984).

The wide distribution of deposits associated with subaqueous outwash systems and blankets of laminated silty clay and fine sand well outside the limits of marine incursion, indicate that proglacial lakes abutted the ice margin during glacial retreat (see also Henderson, 1973). Several different types of evidence suggest as far north as Omphah and Clyde Forks in the northern part of the study regions these proglacial waters originated in the Lake Ontario basin.

First, except for the possibility of blockage by a former lobe of ice, there are no topographic barriers north of present day Lake Ontario to prevent waters impounded in the isostatically depressed Ontario basin from spreading northward into the study region. When the maximum Iroquois water plane of 225.5 m at Pancake Hill (Coleman, 1936; Miryech, 1962; Leyland, 1984) is projected approximately 40 km northeastward over the study region using an isobase trend of N100°E and an uplift gradient of 1.6 m/km (Muller and Prest, 1985), the elevations of low-lying areas between Pancake Hill and the study area are continuously well below the level of the projected plane. Also, the presence of two east-southeast-trending recessional moraines south of Perth and Westport implies that flooding was not impeded by the presence of minor ice lobes.

Second, the ostracod, *Candona subtriangulata* (Benson and MacDonald, 1963) was identified in laminated silty clay from kettle fills associated with subaqueous outwash fan deposits at six sites in the study region (Fig. 10, Table 4) (C. Rodrigues, pers. comm., 1990). *Candona subtriangulata* is characteristic of a large oligotrophic lake having few dissolved solids, such as present day lakes Superior, Huron, Erie, and Ontario (Delorme, 1970, 1978) where it presently lives. Its occurrence in silty clay suggests that these sediments were deposited in a proglacial lake which expanded northward from the Lake Ontario basin.

Third, *Mysis relicta*, a pioneer fresh or brackish water shrimp, able to survive along an ice margin, has been identified in the following lakes, the locations of which are

Table 4. Carbonate abundances in samples collected from exposures of weathered and less weathered till, Clyde Forks-Westport area.

TN sample no	Notes, location	% CaCO ₃ equiv. silt plus clay (Loss)	% CaCO ₃ equiv. fine sand (Loss)	% carbonate* silt plus clay (Chalk)	Sample depth (m)
00AR 0001A	oxidized till	15.9	5.9	19.8	1.0
00AR 0001B	til	26.6	6.7	24.7	2.0
00AR 0001	til	26.3	7.3	23.6	2.0
00AR 0013C	oxidized till	12.1	8.1		1.5
00AR 0013B	unoxidized till	21.7	14.5		3.0
00AR 0013A	unoxidized till	21.1	13.1		3.0
00AR 0013	unoxidized till	21.8	13.8		3.0
00AR 0014E	oxidized till in marble quarry	16.9	8.3	16.5	2.0
00AR 0014D	til	16.3	8.9	13.2	3.0
00AR 0014C	til	16.8	8.3	14.0	4.0
00AR 0014B	til	15.1	8.9	13.8	6.0
00AR 0014A	til	17.3	8.3	16.5	7.0
00AR 0014	til on marble	17.4	8.8		8.0
00AR 0022B	til	25.6	10.2	25.0	0.5
00AR 0022	til	31.9	12.6	29.3	4.0
00KAR0017F	A horizon in till	0.8		1.0	0.05
00KAR0017E	B horizon in till	0.8		1.0	0.15
00KAR0017D	C horizon in till	0.8		1.8	0.5
00KAR0017C	til	1.7		0.3	1.0
00KAR0017B	til	0.0		0.3	1.3
00KAR0017A	til	0.0		0.3	1.8
00KAR0017	til	0.0			2.0
00KAR0004E	humus-rich till	1.7		0.8	0.1
00KAR0004D	red brown till	0.8		0.8	0.3
00KAR0004C	til on beds	0.8		0.9	0.75
00KAR0004B	til	18.3		15.6	1.0
00KAR0004A	til	24.2		21.7	1.25
00KAR0004	blue gray till	31.7		28.5	2.0
00KAR0003D	til	0.8			
00KAR0003C	til	2.5			
00KAR0003B	til	20.0			
00KAR0003A	til	28.7			

* total % carbonate substrate

designated on Figure 10 by the bracketed number — Mackie (1), Palmerston (2), Crotch (3), Sharbot (4), Big Rideau (5), Wolfe (6), Devil (7), Buck (8), Clear (9), Indian (10), and Charleston (11). After evolving in brackish arctic seas, *Mysis relicta* is postulated (Dadswell, 1974) to have migrated into eastern North American fresh water either following marine inundations or by being carried inland through the proglacial waters ponded in front of the advancing ice sheets. At the end of the Pleistocene glaciations, it is thought to have redispersed over eastern North America from several refugia south of the Great Lakes as it was carried northward in the expanding system of proglacial lakes which abutted the retreating glacial margin. Because *Mysis relicta* is unable to swim upstream, it is expected to occur, in this part of eastern Canada, only in those present day lakes that are within the limits of former proglacial lakes originating in the Great Lake basin (Dadswell, 1974).

Two Ontario basin proglacial lake phases have been recognized in the Clyde Forks-Westport region (Fig. 13a, b). First, the presence of a proglacial lake with a limit of over 289 m a.s.l. in the Ompah area, was inferred from the occurrence of *Candona subtriangulata*-bearing silty clay between 289 and 305 m a.s.l. (site 12 on Fig. 10). The presence of *Candona subtriangulata* at Ompah and also of *Mysis relicta* in nearby Palmerston and Mackie lakes (sites 2, 1 on Fig. 10) suggest that this lake was interconnected to Ontario basin water. This lake is interpreted as Lake Iroquois based on the work Millar and Prest (1985) carried out on shoreline elevations between Madoc and Ompah. Second, there is a large delta with topset beds exposed between 198 and 213 m a.s.l. at Joes Lake approximately 25 km northeast of Ompah (Fig. 10). The altitude of this delta marks a water plane in the Clyde River Valley lower than the one interpreted as Lake Iroquois in the Ompah area. When the delta at Joes Lake formed, the ice margin is known to have been between Joes Lake and McCreas Hill which is 4 km north of Joes Lake as the hill would otherwise have acted as a topographic barrier to water flow from the ice margin to the delta. Also present in the Clyde Valley between 198 and 213 m a.s.l. are several subaqueous outwash fan deposits, one of which near French Line (site 13, Fig. 10) is capped by *Candona subtriangulata*-bearing laminated sediment. The occurrence of *Candona subtriangulata* at French Line suggests that the lake in the Clyde Valley also originated in the Lake Ontario basin. This also implies that either before or during the time the ice was receding to the Joes Lake area from the Ompah area, Lake Iroquois had drained to a lower level, as there are no barriers that would have prevented the higher level Lake Iroquois from flooding the Joes Lake area.

Estimates of the northern limits of the two lakes are shown in Figure 13. The outline of the lake interpreted as Lake Iroquois (Fig. 13a) has been drawn by projecting contour lines from the *Candona subtriangulata* occurrence at Ompah using the N100°E isobase trend and a water plane gradient of 1.6 m/km (Muller and Prest, 1985). The ice margin shown in Figure 13a was placed north of the prominent networks of *Candona subtriangulata*-bearing subaqueous outwash fan deposits at Ompah and Lanark (sites 12 and 14, Fig. 10) but its exact position is unknown.

The outline of the lower post-Lake Iroquois lake in the Clyde Valley (Fig. 13b) was drawn by extending contour lines from the Joes Lake delta, again using the N100°E isobase trend and a water plane gradient of 1.6 m/km (Muller and Prest, 1985). As mentioned above the ice margin could be positioned to within 4 km in the Joes Lake area. West of Joes Lake it is placed along the Mount St. Patrick Escarpment. East of Joes Lake, the margin has been depicted as trending east-southeast based on the orientation of the recessional moraine in the Perth region (C on Fig. 10), 30 km to the south.

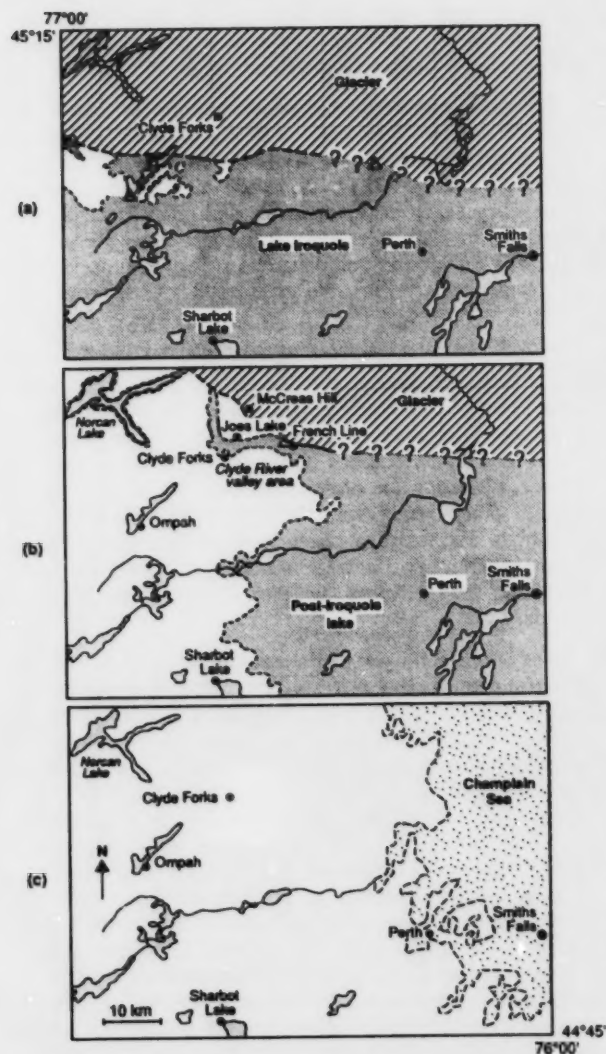


Figure 13. Glaciolacustrine and marine history of the Clyde Forks-Perth region. (a) proposed limits of an Ontario basin lake with a level of over 289 m a.s.l. in the Ompah region correlated with Lake Iroquois (b) proposed limits of a lake with a level between 198 and 213 m a.s.l. in the Clyde Forks area thought to be a post-Lake Iroquois phase; (c) projected limits of the Champlain Sea. Position of the ice margin is speculative, except in the McCreas Hill area on 13(b).

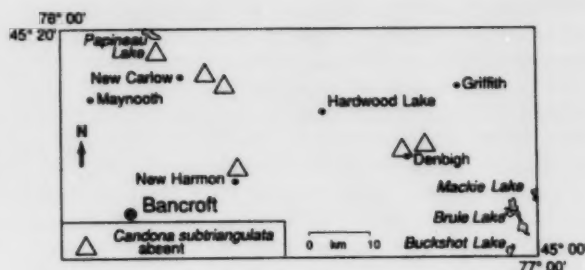


Figure 14. Sites of extra laminated silty clay samples in the Bancroft-Denbigh region. *Candona subtriangulata* is absent at these sites.

The history of the 228-245 m a.s.l. limit lake in the Clyde River Valley (Fig. 13b) is further complicated by formation of terraces on the Joes Lake delta at approximately 198 m a.s.l. The terraces must have formed when the ice margin was still south of McCreas Hill for the reason stated above. They possibly formed when (1) a lower outlet in the Covey Hill area was uncovered, allowing the one post-Iroquois phase occupying the Clyde River Valley to drain to another lower phase, or (2) the level of post-Iroquois phase fell locally in the Clyde Forks area due to different rates of isostatic rebound between the Clyde Forks area and the Lake Ontario basin.

An attempt was made to trace the northern limit of Lake Iroquois in the region west of, and contiguous with the southern part of the Clyde Forks map area (Fig. 14). Extra silty clay samples were collected in the Bancroft-Denbigh region. (Except for Mackie Lake which was found to contain *Mysis relicta*, Dadswell's (1974) study of micro-fauna assemblages in modern lakes did not cover this region.) The absence of *Candona subtriangulata* at the sites shown in Figure 14 suggests that Lake Iroquois did not inundate the Denbigh-Bancroft region except in the Mackie Lake area.

It is likely that in addition to Ontario basin lakes, numerous local proglacial lakes existed in the northern part of the study region. After Lake Iroquois drained, glacial meltwater would have been ponded locally against the retreating ice margin in low-lying areas presently draining northward into the Madawaska and Mississippi valleys. For example, as depicted in Figure 12b, a large proglacial lake likely occupied the Norcan basin, northwest of Joes Lake, at the time the post-Lake Iroquois lake existed in the Clyde Forks area.

Marine incursion

When the ice retreated from the lower St. Lawrence Valley, marine waters invaded the St. Lawrence Lowlands allowing Ontario basin waters to drain from the study area and the Champlain Sea to develop. Radiocarbon dates on marine shells indicate that marine waters invaded the Clayton area just north of the study region approximately 12.2 ka (Fulton and Richard, 1987) and had regressed from the area just east of Smiths Falls by 11.1 ka (Sharpe, 1979).

Marine shells were identified in a gravel deposit south of Perth (E.P. Henderson, pers. comm., 1989) and whale bones were found by Coleman (1901) near Smiths Falls. No other paleontological or sedimentological evidence was discovered as part of this study to establish accurately the limits of marine incursion. Based on the presence of laminated sediment, the elevations of marine shell sites at or near marine limit in the Carleton Place (Richard, 1990) and Merrickville (Sharpe, 1979) areas, and by using the N100°E isobase trend and an uplift gradient of 1.6 m/km (Muller and Prest, 1985), a marine limit has been established that crosses the Perth area at approximately 137 m (Fig. 13c). Some strandlines have been recognized north and northwest of Smiths Falls within the area thought to have been inundated by the Champlain Sea.

DRIFT COMPOSITION

Mapping of drift composition was based on systematic sampling of glacial sediments from exposures usually 1-2 m below the surface (Fig. 15). In this study till was sampled wherever possible because it is considered to be the sediment most representative of the composition of the debris load carried by the glacier and, hence, in glaciated terrain, of underlying bedrock or bedrock immediately up-ice (Shilts, 1973). Because the earlier sampling programme was designed for environmental purposes, sampling strategy differed from a study designed for mineral exploration purposes alone. The rationale behind the earlier sampling plan was to collect, where till was covered by a mantle of late- or postglacial sediments, those sediments that have the greatest influence on the near-surface environment. Thus, some samples of ice-contact glaciofluvial sediments, glaciolacustrine or marine silty clay sediments were collected where they formed the predominant surface cover or till was unavailable for sampling. Because sediments other than till have undergone at least one cycle of fluvial transport prior to deposition, their composition is thought to differ more from the glacial load or the underlying bedrock than would till (Shilts, 1984b). In addition, as discussed later, part of the fine material in coarse glaciofluvial sediments is generated by postdepositional weathering. The high exchange capacity of this material gives these sediments background cation concentrations considerably above those of adjacent till or glaciolacustrine/glaciomarine sediments (Shilts, 1973). Data for a small number of non-till sediment samples, the locations for which are shown in Figure 15, were used to generate the regional trace element and carbonate distribution maps presented below. Because the sites of non-till samples are widely scattered, any compositional disparities caused by changes in the sediment facies sampled are not expected to alter significantly patterns of regional variations in drift composition.

The results of this study show that drift composition is controlled by: (1) composition of the underlying and up-ice bedrock; (2) glacial transport processes; (3) sediment facies sampled; and (4) degree of weathering. These findings support the conclusions of Kettles and Shilts (1989). For individual drift samples, one or more of these factors may affect composition; some examples are presented in the discussions that follow.

Pebble lithology

The distribution patterns of small pebbles (2-5.6 mm) of selected lithologies in drift show that glacial dispersal can be observed at two scales in the study region — regional (tens of kilometres) and local (1-2 km). The distribution of Paleozoic carbonate clasts in drift (Fig. 16, in pocket) reflects the effects of glacial transport on a regional scale. Concentrations of Paleozoic carbonate clasts in drift are high over Paleozoic bedrock (>60%) and also over an area underlain by Precambrian terrane which extends over 20 km west or southwest of the Precambrian-Paleozoic boundary (>20%). Outside the study region, traces of Paleozoic carbonate may still be detected in drift overlying Precambrian terrane over 70 km west of the Paleozoic-Precambrian boundary (Kettles and Shilts, 1989).

In most cases, highest concentrations of clasts of Precambrian marble, or mafic or felsic bedrock of intrusive or metavolcanic provenance are found close to the relevant outcrop areas (Fig. 17, 18, 19, in pocket). Detailed studies of the dispersal in drift, of marble and other Precambrian lithologies in the Clyde Forks area consistently show that detectable glacial transport distances are on the order of 1-2 km (Sinclair, 1979; DiLabio et al., 1982; Gleeson et al., 1989).

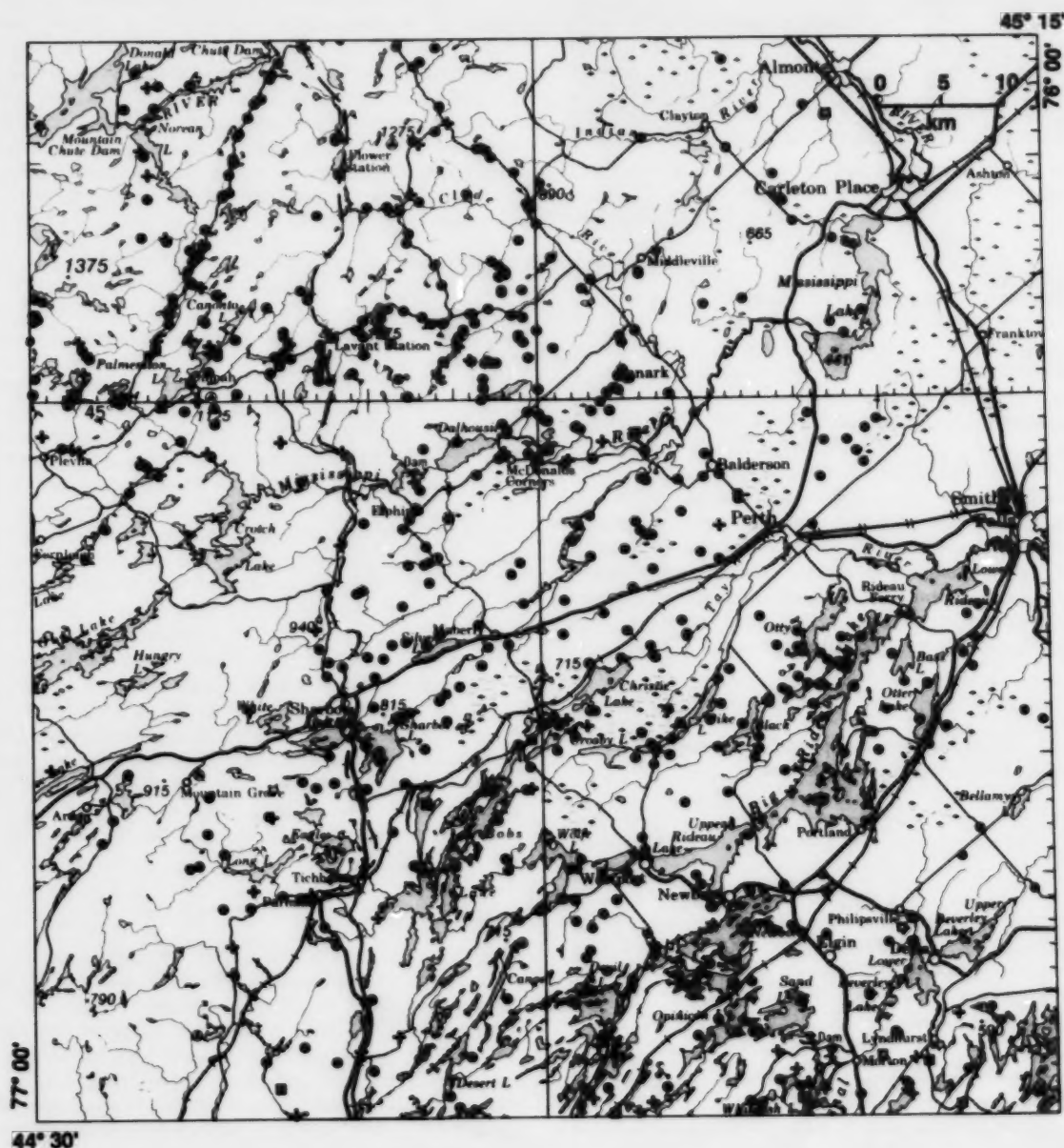
Where concentration of Precambrian clasts in drift (Fig. 17, 18, 19) overlying Paleozoic terrain is high, there are at least two possible sources. Some Precambrian clasts in till overlying Paleozoic terrain were possibly derived from Precambrian bedrock northeast of the study area in Quebec, reflecting the presence of a far-travelled component. In other cases, especially where concentrations are very high, Precambrian clasts were likely derived from Precambrian inliers, a large number of which exist in Paleozoic terrane close to the Paleozoic-Precambrian boundary.

The strong influence of Paleozoic lithologies on glacial sediment composition over a wide area can be attributed to the physical characteristics of these strata (Shilts, 1984a). Paleozoic sedimentary rocks, composed predominantly of fine grained calcite and dolomite, are heavily jointed and in many cases thinly bedded. Because these lithologies are highly susceptible to abrasion and plucking, large quantities of Paleozoic rock became incorporated into the glacier. During transport, continued clast-to-clast and clast-to-bedrock contact continued to produce the fine carbonate debris that was eventually separated from samples and analyzed during this study, the analyses forming the basis for the dispersal maps. In contrast, Precambrian crystalline lithologies produced much smaller quantities of glacial debris due to the hard, massive, coarse grained nature of these units. These same physical characteristics, however, allowed some part of the small quantity of debris produced from Precambrian bedrock to resist breakdown during glacial transport and be carried long distances, as evidenced by the presence of Precambrian clasts in drift (Fig. 17, 18, 19) overlying Paleozoic terrain.

Carbonate content

Carbonate content of the silt plus clay-sized fraction of glacial sediments was determined as part of this study. Although care was taken to sample glacial sediments that were as unweathered as possible, it is possible that low carbonate concentrations in some individual samples may reflect weathering rather than source composition. Glacial

sediments in this region are generally severely leached to depths of 1-1.5 m, below which there is usually little or no depletion of carbonate, even in drift that shows signs of weathering (Shilts, 1984a; Kettles and Shilts, 1989). Indications of weathering include colour change from grey to grey-brown, precipitation of oxides, and the presence of chemically disaggregated, coarsely crystalline clasts (Fig. 20).



Sample sites

- till
- silty clay
- + sand/gravel

Figure 15. Sample sites in the Clyde Forks-Westport area, with sediment type indicated.



Figure 20. A disaggregated boulder of Precambrian gneiss in weathered till near Black Donald Lake. GSC 205253

Carbonate measurements on sample profiles through some of the best exposures of both carbonate-rich and carbonate-poor till are shown in Table 5. In some cases, where carbonate content of the unweathered or less weathered samples is below 1%, concentrations of carbonate may appear to increase to levels of 1-2% in the samples collected in the A and B horizons of the solum (for example, 88KAR3517 and KAR3534, Table 5). When the fine fractions of the same samples were X-rayed no carbonate minerals were detected. In the exposures where increased carbonate levels in the solum are observed, A and B soil horizon samples invariably contain high levels of noncarbonate carbon. It is likely that these apparent increases in carbonate content reflect some loss of precision associated with the analytical method used.

Table 5. Locations and descriptions of *Candona subtriangulata*-bearing silty clay samples.

Site	Nearest town	Elevation		* Number of valves
		metres	feet	
12	Ompah	289-305	950-1000	15
13	French Line	198-213	650-700	8
14	Lanark	153	500	9
15	Clarendon Station	229-244	750-800	6
16	Fallbrook	175	575	14
17	Morton	122	400	12

*Based on fraction of residue >180 µm from 200 g of dry sediment

Similar to patterns of enrichment of Paleozoic carbonate clasts in drift, concentrations of silt plus clay-sized carbonate are generally high (commonly >25%) in glacial sediments overlying Paleozoic terrane and overlying Precambrian terrain in an area which extends over 20 km west and southwest of the Precambrian-Paleozoic boundary (Fig. 21, in pocket). Similar patterns of enrichment for the Clyde Forks-Westport region were produced during the earlier glacial sediment sampling survey which covered a large part of southeastern Ontario (Fig. 22) (Shilts, 1984a; Kettles and Shilts, 1989). With most samples having concentrations >5% CaCO₃ equivalent, drift overlying the Central Metasedimentary Belt bedrock in the Clyde Forks-Westport region is generally more calcareous than drift overlying lithologically similar bedrock farther west in the Minden-Haliburton region where the Paleozoic carbonate content of drift is negligible (Shilts, 1984a; Kettles and Shilts, 1989) (Fig. 21, 22).

Within the study region, concentrations of silt plus clay-sized carbonate are particularly high (commonly >50%) in drift overlying two major Precambrian marble belts, one north and west of Perth and the other northwest of Ompah. Over the marble belts, concentrations of Paleozoic carbonate and Precambrian marble clasts in drift are both elevated, which likely accounts for the extremely high levels of carbonate. Areas with high concentrations of granule-sized Precambrian marble clasts (Fig. 17) in drift, however, correspond most closely to areas where drift is enriched in silt plus clay-sized carbonate (Fig. 21) which suggests that Precambrian marble is the main source of fine-size carbonate in drift over the marble belts. The effect of Precambrian marble on the carbonate content of the fine fraction of drift is much more pronounced in this part of the Central Metasedimentary Belt than it is farther west. Carbonate concentration in drift overlying the large marble belts in the Bancroft and Haliburton areas is consistently low (less than 5% CaCO₃ equivalent; Fig. 22) (Shilts, 1984a; Kettles and Shilts, 1989). The reasons for the range of carbonate enrichment from different Precambrian marbles are at present unknown, but probably relate to the degree of lithologic generalization on the bedrock maps; that is, there may be a greater admixture of clastic strata in the "marble" belts to the west.

Texture of till

Regional variations of till texture are influenced by the composition of the underlying bedrock and also by processes associated with glacial transport (Shilts, 1984a; Kettles and Shilts, 1989). As would be expected, concentration of clay- and silt-sized detritus is high in the few till samples collected in Paleozoic terrain (Fig. 23a, b, in pocket). Concentration of clay-sized and, in some areas, silt-sized materials is also high in samples from both calcareous and noncalcareous Precambrian terranes, collected in till which has high concentrations of both Paleozoic clasts and silt plus clay-sized carbonate (Fig. 16, 22). For unknown reasons, in the southern part of the Clyde Forks map area, carbonate-poor tills are uniformly silty (30-50%) in spite of overlying Precambrian bedrock of diverse lithologies (Fig. 23b, 5a). In the Westport map area, tills rich in

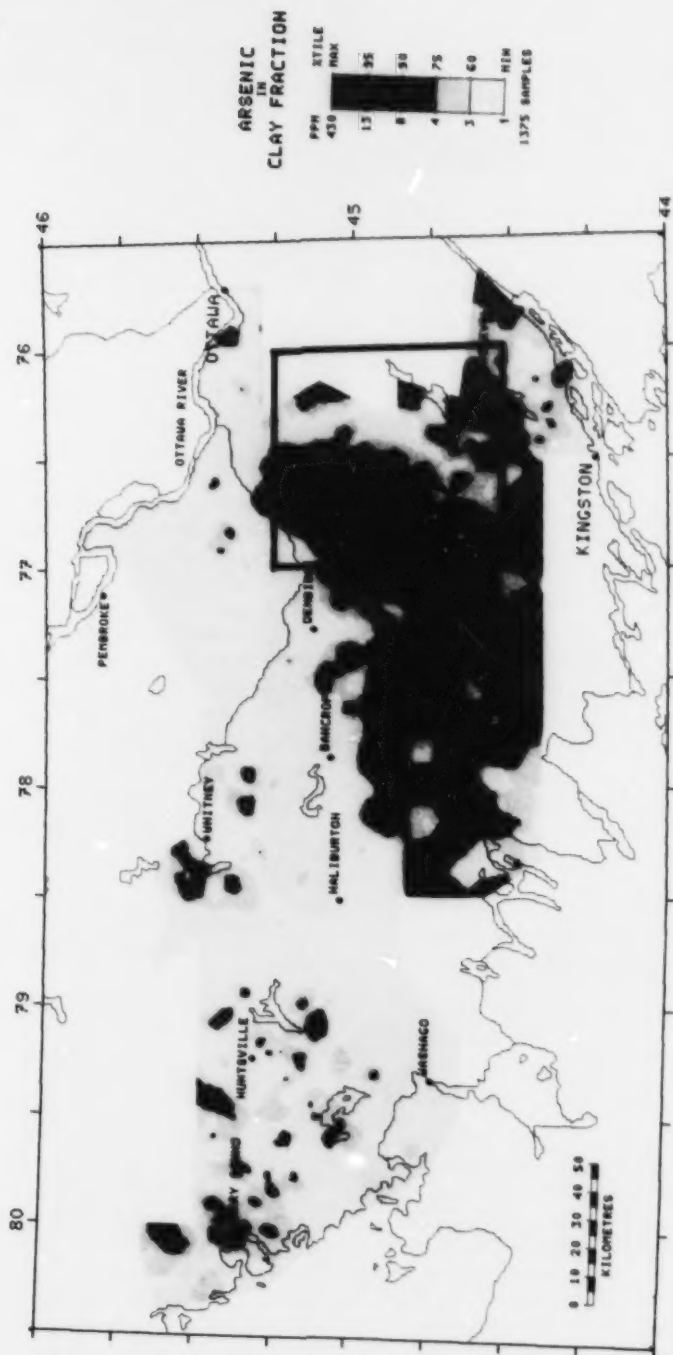


Figure 26. Distribution of As in the clay-sized (<0.002 mm) fraction of glacial sediments over southeastern Ontario, after Kettles and Shillis (1983, 1989). Present study area is outlined.

Paleozoic clasts, lying on Precambrian bedrock, are particularly fine grained. To the west, outside the area of Paleozoic carbonate enrichment, the sand content in the matrix of shield tills is generally greater than 75% (Fig. 23c, in pocket).

Trace element composition

Variation in the trace element composition of drift over most parts of the study region can be related to composition of underlying or nearby bedrock. Concentration of trace elements in the clay-sized fraction is uniformly low in samples from the unmetamorphosed Paleozoic terrane in the eastern part of the study region. In contrast, trace element level is relatively higher in till resting on the crystalline rocks of the Canadian Shield in the western part of the study region. Even on the Shield, however, concentration of trace elements is low in areas characterized by Paleozoic carbonate-enriched drift, especially in clay-rich tills in the Westport map area (Kettles, 1990). The distribution of U and Mn in drift (Fig. 24, 25, in pocket), for example, illustrates the regional variation described above.

Unmetamorphosed Paleozoic sedimentary bedrock underlying and to the east of the study region is dominated by supracratonic platform dolostone, limestone, sandstone, and minor shale (Poole et al., 1970). Within these rock types, trace element concentrations are generally low (Mason, 1962, Table 6.5). Also, although carbonate minerals tend to be glacially comminuted to fine sand and silt-size (Dreimanis and Vagners, 1971), it is possible that in the large volume of debris derived from Paleozoic carbonate rock, enough carbonate debris was glacially comminuted to clay-size to noticeably affect the composition of the clay-sized fraction. Carbonate minerals were detected in the clay-sized fraction of the small number of carbonate-rich samples analyzed using X-ray diffraction methods (R.N. DeLabio, Geological Survey of Canada, pers. comm., 1987).

In order to determine, using drift prospecting methods, true mineral potential in areas where Paleozoic carbonate-enriched till overlies Precambrian bedrock, it may be necessary to normalize trace element data after dividing the study region into two areas, one where glacial sediments are enriched in Paleozoic debris and the other where they are Paleozoic carbonate-poor. For example, in the Athabasca basin area of Saskatchewan, where there are four geologically distinct terranes, Coker and Dunn (1983) rescaled geochemical data for lake sediments and lake waters prior to plotting trace element distribution maps.

In Precambrian terrane, highest concentrations of most trace elements are found in drift overlying those parts of the Central Metasedimentary Belt within the Clyde Forks and Sharbot Lake map areas. Some enrichment likely reflects high background concentrations of trace elements in the underlying bedrock (Barnett, 1989, Appendix D). The Clyde Forks-Ompah area, for example, forms the eastern extension of large areas of As- (Fig. 26), Hg-, Cu-, and Fe-rich (not shown) drift which broadly outline the belts of metavolcanic and metasedimentary rocks of this area (Hornbrook et al., 1986; Kettles and Shilts, 1989).

Distribution patterns of Zn (Fig. 27, in pocket), Co (Fig. 28, in pocket), and Cd (Fig. 29, in pocket) also can be related readily to underlying bedrock composition. The patterns of Zn and Cd enrichment in drift correspond closely to each other and to the distribution patterns of glacial sediments with high concentrations of marble clasts and to Precambrian marble outcrop areas (Fig. 17). DiLabio et al. (1982) showed that Zn and Cd are closely related in sphalerite occurrences in the marble. In contrast, almost all areas of Co-enriched drift are found overlying either the Robertson Lake Mylonite Zone or mafic intrusive or metavolcanic rocks.

Some areas of high Co correspond well to areas with high concentrations of Precambrian mafic clasts in glacial sediments (Fig. 18). In many regions, also, there are high concentrations of Pb in drift (Fig. 30, in pocket) over marble bedrock and U and Mo over Precambrian felsic bedrock (Fig. 24, 31, in pocket).

Some As (Fig. 32, in pocket), Au (Fig. 33, in pocket), Hg (Fig. 34, in pocket), Ag (Fig. 35, in pocket), Cu (Fig. 36, in pocket), and Fe (Fig. 37, in pocket) enrichment in drift in the Clyde Forks and Sharbot Lake map areas likely reflects mineralization in the underlying bedrock. High levels of the above elements are found in drift overlying or near Robertson Lake Mylonite Zone in areas where many showings of gold and other sulphide minerals in bedrock are known (Carter et al., 1980; Sangster, 1982; Gleeson et al., 1989) (Fig. 5a). In the study region, mineralized occurrences of Cu-Sb-Au-Ag and Cu-Sb-Au-Hg have been discovered, containing tetrahedrite, chalcopyrite, pyrite and gold (Gleeson et al., 1989) (Fig. 6), but they are generally carbonate-hosted, whereas drift with high concentrations of the above elements more commonly overlies mafic bedrock. In this case, high concentrations of these elements may indicate that this type of mineralization occurs in mafic bedrock in this area. Gold, pyrite, and arsenopyrite are also known in gabbro-hosted quartz-ferroan carbonate veins, in trondhjemite-hosted quartz veins, and in mafic mylonite-hosted massive sulphide zones (Gleeson et al., 1989).

Concentration of Cr in drift (Fig. 38, in pocket) is low over Paleozoic rocks. Over Precambrian bedrock, however, regional variations of Cr in the clay fraction of drift are not easily related to the sources of composition variation in bedrock outlined above. For unknown reasons, the pattern of Ni-rich drift in the McDonalds Corners area (Fig. 39, in pocket) corresponds closely to the distribution pattern of drift enriched in marble clasts. Rock sequences in most parts of the study area are complexly interbedded and possibly small metavolcanic units interbedded with marble in the McDonalds Corners area are Ni-enriched.

In contrast to the other trace elements, the content of Au in drift (Fig. 33) was determined for the silt plus clay fraction of the samples for the reasons outlined previously. Although the distribution of Au in drift appears to indicate source(s) in the Robertson Lake Mylonite Zone, in other parts of the study area, the true pattern of Au distribution in

drift may be suppressed by the presence of large concentrations of silt- and clay-sized Paleozoic carbonate debris. Masking of the geochemical signature by glacially transported exotic debris has been noted previously in the Pitz Lake region (Shilts, 1984b) and the Beardmore-Geraldton area, northern Ontario (Thorleifson and Kristjansson, 1988). The distribution pattern of glacial sediments with low levels of Au seems to mimic particularly closely the distribution pattern of drift with high levels of silt plus clay-sized carbonate (Fig. 21), as is the case in the Beardmore-

Geraldton area. Concentrations of gold, for example, are low where carbonate concentrations (<0.063 mm) are uniformly very high ($>40\%$) overlying belts of marble northeast and southwest of McDonalds Corners. Elsewhere, concentrations of gold in drift are high (>10 ppb) in the southern part of the Clyde Forks map area, where concentrations of silt plus clay-sized carbonate are generally low.

Some variation in trace element composition of glacial sediments may also result from postglacial weathering (Kettles and Shilts, 1989). In individual samples, concentra-

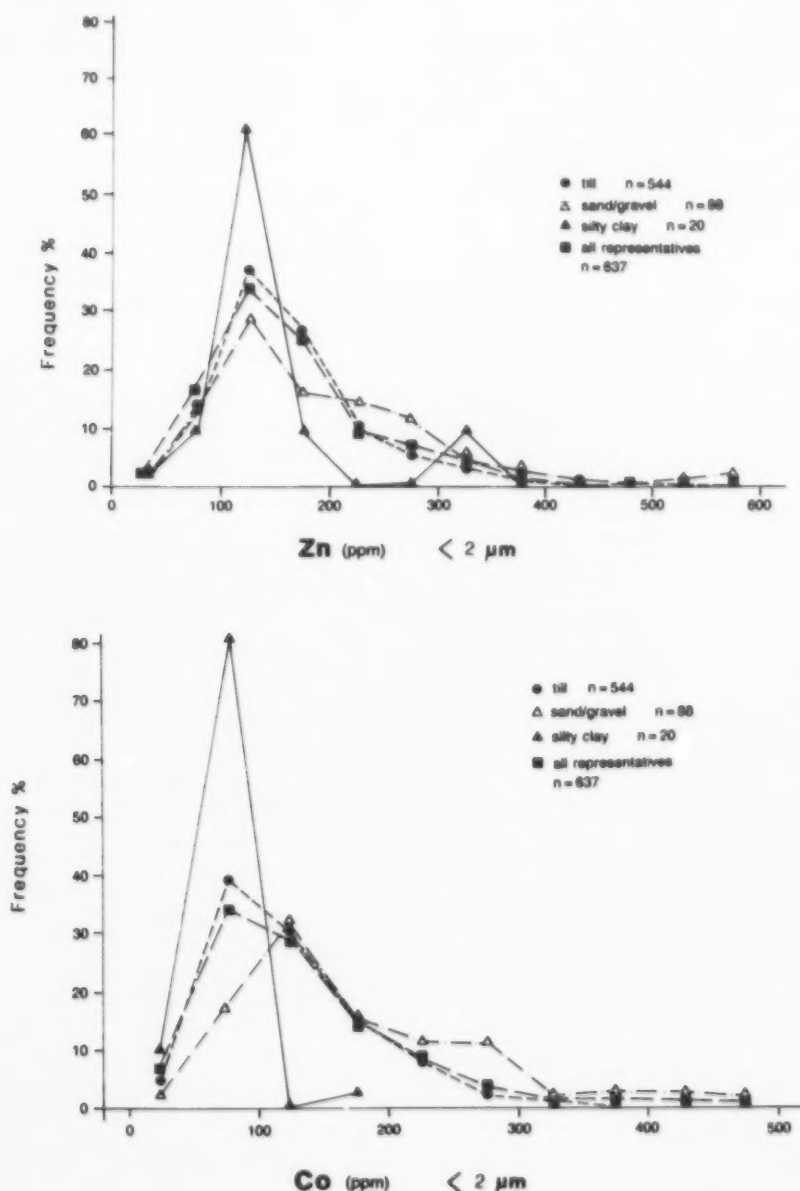


Figure 40. Frequency histograms of As and Co abundances in all representative samples, as well as in separate groups comprised of till, glaciofluvial sand and gravel, and glaciolacustrine or marine silty clay samples.

tions of Fe, sometimes Mn, and commonly other trace elements, tend to be high in samples of glacial sediments that were described in the field as being highly weathered. High concentrations of Fe and other trace elements most likely indicate the presence of secondary alteration products in the clay-sized fraction of the sample.

Another cause of variation in chemical composition of drift can be related to sediment facies sampled (Kettles and Shilts, 1989). Frequency histograms for Zn and Co data for samples of the different sediment groups, which typify results for most trace elements, are shown in Figure 40. There is a narrow range of trace element concentrations in glaciolacustrine and glaciomarine sediment samples in comparison to till and glaciofluvial ice contact sand and gravel. The wide range of concentrations in samples collected in till and sand or gravel likely represents local variability in bedrock lithologies either at the sample site or up-ice from it. The lack of compositional variation in glaciolacustrine or marine sediments is thought to reflect homogenization associated with their deposition (Kettles and Shilts, 1989).

Glaciofluvial sediment samples have higher trace element concentrations in the clay fraction, on average, than do samples of till collected nearby (Fig. 40). This is because some proportion of the clay-sized detritus in sand and gravel deposits consists of weathering products, many of which are metal-enriched (Shilts, 1973; Kettles and Shilts, 1989).

CONCLUSIONS AND RECOMMENDATIONS

The Quaternary deposits in the Clyde Forks-Westport area are considered to be Late Wisconsinan or younger (Fulton et al., 1986). Predominant ice flow direction during the Late Wisconsinan, as evidenced by the orientation of striae and drumlins, was south-southwestward. Till is the most widespread glacial deposit. Only one stratigraphic unit has been recognized which was identified as the Fort Covington Till in the nearby Merrickville area. Till generally forms a discontinuous cover, commonly less than 1.5 m thick. Till deposits are thicker (>1.5 m) where drumlinized and also in several discontinuous, east- to east-southeast-trending belts. The most prominent of these belt lies in the southwestern corner of the study area and forms part of the Dummer Moraine while two others, also interpreted as recessional moraines, cross the study region south of Perth and Westport. Glaciofluvial sand and gravel deposits are widespread, commonly as leese deposits, small isolated kames, kame terraces or esker ridges, and subaqueous outwash fan deposits. Prominent networks of discontinuous deposits are associated with two long subaqueous outwash systems, one of which extends from Tamworth northeastward 75 km to the Poland area whereas the other extends from southeast of Elphin to the Lanark area. Another large deposit occurs west of Charleston Lake. Elsewhere, in some low-lying areas near Perth and southeast of Westport, there are blankets of laminated glaciolacustrine silty clay and fine sand. Similar deposits in the Perth-Smiths Falls region may have been deposited in the Champlain Sea (Henderson, 1973).

The presence of the east- to east-southeast-trending belts of thick till interpreted as recessional moraines suggests that the glacial margin was oriented nearly east-southeast as the ice retreated at least as far north as Perth. A retreating ice mass with an east- to east-southeast-trending ice margin is more compatible with Chapman and Putnam's (1966) and Prest's (1970) view of a deglaciation in the area north of Lake Ontario than Gadd's (1980) where the retreating ice mass had a lobate margin.

The occurrence of the ostracode, *Candona subtriangulata* in laminated silty clay (C. Rodrigues, pers. comm., 1989), the presence of *Mysis relicta* in some present day lakes (Dadswell, 1974), and the lack of topographic barriers to impede flooding suggest that as the ice retreated as far north as Ompah and Clyde Forks the proglacial waters abutting the ice margin were interconnected with the main Ontario basin water. On the basis of location of shoreline features and occurrences of *Candona subtriangulata* and *Mysis relicta*, two Ontario basin lake phases have been recognized: (1) a lake with a level over 289 m a.s.l. in the Ompah area thought to be Lake Iroquois, and (2) a lake with a maximum level of 198-213 m in the Clyde Forks area, thought to be a lower post-Lake Iroquois phase.

Coleman (1901) and E.P. Henderson (pers. comm., 1989) found whale bones and marine shells, respectively, near Smiths Falls indicating that the Champlain Sea covered part of the Perth map area. No other paleontological data that could be used to determine limits of marine incursion were found as part of this study. By extending contour lines from marine-shell bearing shoreline features at or near marine limit in the Carleton Place area using the N100°E isobase trend and an uplift gradient of 1.6 m/km (Muller and Prest, 1985), a marine limit has been delimited which crosses the Perth area at 137 m a.s.l. It is possible that with examination of fauna in modern lakes of the Perth region, limits of marine incursion could be more closely pinpointed. Certain crustacean species have been noted to occur only in lakes formerly inundated by marine waters (Dadswell, 1974).

The effects of glacial transport on drift composition are reflected most strongly in regional variations in the contents of Paleozoic clasts (2.0-5.6 mm) and silt plus clay-sized (<0.063 mm) carbonate in all glacial sediments and also the texture of till. Concentrations of Paleozoic clasts and silt plus clay-sized carbonate are high in all glacial sediments and till is more fine-grained overlying Paleozoic bedrock and also over an area of Canadian Shield terrane which extends 20 km west and southwest of the Paleozoic-Precambrian boundary. Large quantities of debris derived from the easily-eroded Paleozoic dolostones and limestones in the eastern part of and to the east of the study area were incorporated into the glacier and transported southwestward. West of the study area, traces of Paleozoic carbonate were still detected in drift over Precambrian terrane 70 km west of the Precambrian-Paleozoic boundary (Kettles and Shilts, 1989). In contrast, high concentrations of Precambrian clasts of various lithologies are found close to the outcrop area of each bedrock type. Detectable dispersal trains of selected Precambrian lithologies are of the order of 1-2 km (Sinclair, 1979; DiLabio et al., 1982; Gleeson et al., 1989). The

production of weak dispersal trains from Precambrian lithologies likely reflects low sediment production in the hard crystalline shield terrain.

The trace element content of the clay-sized fraction of drift usually reflects composition of the underlying or nearby bedrock. Trace element levels in drift are generally low overlying Paleozoic terrane compared to levels in drift overlying Precambrian bedrock. In Canadian Shield terrane, glacial sediments overlying Precambrian marble belts commonly have high levels of Zn and also Precambrian marble clasts. Elsewhere, drift overlying or near the Robertson Lake Mylonite Zone is enriched in As, Au, Hg, Cu, Pb, and Fe. Over or near the Robertson Lake Mylonite Zone, some enrichment may reflect mineralization as gold and base metal occurrences in bedrock are known in these areas.

With more detailed mapping of trace element dispersal patterns, the effects of glacial transport on distribution patterns of trace elements in drift can be discerned. For example, in drift over Precambrian bedrock near Westport, trace element levels are generally low in areas where the till is fine grained and glacial sediments have high concentrations of Paleozoic clasts and silt plus clay-sized carbonate. In these areas, the geochemical signature of the till imparted by Precambrian lithologies is partially masked by the dispersal train of Paleozoic carbonate. In more detailed exploration studies in areas of Paleozoic carbonate-enriched drift, the mixed population of calcareous and noncalcareous samples should be normalized or treated as two separate populations for better results.

This study was carried out primarily for exploration purposes. Highest concentrations of Au, As, Cu, Pb, Hg, and other trace elements are found in drift overlying or near the Robertson Lake Mylonite Zone, especially over the southern edge of the Clyde Forks map area, in the north-west corners of both the Sharbot Lake and Tichborne map areas, and in the Pennick Lake area north of Sharbot Lake. Further mineral exploration work is recommended in the vicinity of the Robertson Lake Mylonite Zone as its mineral potential is largely unrealized. Because road access is poor, few samples were collected. Sample coverage is especially poor in the southeastern part of the Sharbot Lake map area, an area which encompasses the Robertson Lake Mylonite Zone and lies between the two areas of metal-rich till.

REFERENCES

- Allen, J.R.L.
1984: Sedimentary structures: their character and physical basis; *Developments in Sedimentology* 30, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, v. 2, 663 p.
- Anderson, T.W., and Lewis, C.F.M.
1985: Postglacial water-level history of the Lake Ontario basin; in *Quaternary Evolution of the Great Lakes*, (ed.) P.F. Karrow and P.E. Calkin; Geological Association of Canada, Special Paper 30, p. 233-253.
- Anderson, T.W., Mott, R.J., and Delorme, L.D.
1985: Evidence for a pre-Champlain Sea glacial lake phase in Ottawa Valley, Ontario and its implications; in *Current Research, Part A: Geological Survey of Canada, Paper 85-1A*, p. 239-245.
- Baer, A.J., Poole, W.H., and Sanford, B.V.
1971: Riviere Gatineau, Quebec-Ontario, Sheet 31; Geological Survey of Canada, Map 1334A, scale 1:1 000 000.
- Banerjee, I. and McDonald, B.C.
1975: Nature of esker sedimentation; in *Glaciofluvial and Glaciolacustrine Sedimentation*; (ed.) A.V. Jopling and B.C. McDonald; Society of Economic Paleontology and Mineralogy, Special Publication 23, p. 304-320.
- Barnett, P.J.
1989: Quaternary geology of the Bancroft area, southern Ontario; Ontario Geological Survey, Report 262, 93 p.
- Barnett, P.J. and Clarke, W.S.
1980: Quaternary geology of the Renfrew area; Ontario Geological Survey Preliminary Map, P.2365, Geological Series, scale 1:50 000.
- Benson, R.H. and MacDonald, H.C.
1963: Post-glacial (Holocene) ostracodes from Lake Erie; University of Kansas, Paleontological Contributions, v. 4, p. 1-26.
- Bostock, H.S.
1970: Physiographic subdivisions of Canada; in *Geology and Economic Minerals of Canada*, (ed.) R.J.W. Douglas; Geological Survey of Canada, Economic Geology, No. 1, p. 9-30, Map 1245A.
- Boulton, G.S.
1974: Processes and patterns of glacial erosion; in *Glacial Geomorphology*, (ed.) D.R. Coates; Publications in Geomorphology, State University of New York, Binghamton, New York, p. 41-87.
- Carter, T.R., Colvine, A.C., and Meyn, H.D.
1980: Geology of base metal, precious metal, iron and molybdenum deposits in the Pembroke-Renfrew area; Ontario Geological Survey Mineral Deposits, Circular 20, 186 p. Accompanied by Preliminary Map P. 2211, scale 1:126 720.
- Chapman, L.J. and Putnam, D.F.
1966: The Physiography of Southern Ontario; University of Toronto Press, 386 p.
- Clarke, P. and Karrow, P.F.
1984: Late Pleistocene water bodies in the St. Lawrence Lowland, New York, and regional correlations; Geological Society of America Bulletin, v. 95, p. 805-813.
- Coker, W.B. and Dunn, C.E.
1983: Lake water and lake sediment geochemistry, NEA/IAEA Athabasca Test Area; in *Uranium Exploration in Athabasca Basin, Saskatchewan, Canada*, (ed.) E.M. Cameron; Geological Survey of Canada, Paper 82-11, p. 117-126.
- Coleman, A.P.
1901: Marine and freshwater beaches of Ontario; Geological Society of America Bulletin, v. 12, p. 129-146.
1904: Iroquois beach in Ontario; Geological Society of America Bulletin, v. 15, p. 347-368.
1936: Lake Iroquois; Ontario Department of Mines, 45th Annual Report, v. 2, pt. 7, p. 1-36.
- Dadswell, M.J.
1974: Distribution, ecology and postglacial dispersal of certain crustaceans and fishes in eastern North America; National Museum of Natural Sciences, Publication in Zoology, no. 11, 110 p.
- Delorme, L.D.
1970: Freshwater ostracodes of Canada, part 111; Family Candonidae; Canadian Journal of Zoology, v. 48, p. 1099-1127.
1978: Distribution of freshwater ostracodes in Lake Erie; Journal of Great Lakes Research, v. 4, p. 216-220.
- DiLabio, R.N.W.
1988: Residence sites of gold, PGE, and rare lithophile elements in till; in *Prospecting in Areas of Glaciated Terrain — 1988*, (ed.) D.R. MacDonald and K.A. Mills; The Canadian Institute of Mining and Metallurgy, p. 121-140.
- DiLabio, R.N.W., Rencz, A.N., and Egginton, P.A.
1982: Biogeochemical expression of a classic dispersal train of metalliferous till near Hopetown, Ontario; Canadian Journal of Earth Sciences, v. 19, p. 2297-2305.

Dreimanis, A.

- 1962: Quantitative gasometric determination of calcite and dolomite by using Chittick apparatus; *Journal of Sedimentary Petrology*, v. 32, p. 520-529.

Dreimanis, A. and Vagners, U.J.

- 1971: Bimodal distribution of rock and mineral fragments in basal till; in *Till, a Symposium*, (ed.) R.P. Goldthwait; Ohio State University Press, p. 237-250.

Easton, R.M.

- 1987: Precambrian geology, Clyde Forks, Frontenac, Lanark and Renfrew counties; Ontario Geological Survey, Open File Map 96, scale 1:50 000, NTS 31F/02.
1988: Geology of the Darling area, Lanark and Renfrew counties; Ontario Geological Survey, Open File Report 5693.
1990: Precambrian geology, Clyde Forks area; Ontario Geological Survey, Preliminary Map 3092.

Easton, R.M. and MacMaster, G.

- 1987: Precambrian geology, Sharbot Lake, Ontario; Ontario Geological Survey, Open File 97, scale 1:50 000, compilation 1987.

Foscolos, A.E. and Barefoot, R.R.

- 1970: A rapid determination of total organic and inorganic carbon in shales and carbonates; Geological Survey of Canada, Paper 70-11, 14 p.

Freeman, E.B. (ed.)

- 1979: Geological highway map, southern Ontario; Ontario Geological Survey, Map 2441, scale 1:800 000.

Fulton, R.J. and Richard, S.H.

- 1987: Chronology of late Quaternary events in the Ottawa region; in *Quaternary geology of the Ottawa region, Ontario and Quebec*, (ed.) R.J. Fulton; Geological Survey of Canada, Paper 86-23, p. 24-30.

Fulton, R.J., Gadd, N.R., Harington, C.R., Kettles, I.M., Richard, S.H., Rodrigues, C.G., Rust, B.R., and Shilts, W.W.

- 1986: Summary of the Quaternary of the Ottawa Region; in *Quaternary Geology of the Western Basin of the Champlain Sea*, (ed.) R.J. Fulton; Geological Association of Canada-Mineralogical Association of Canada-Canadian Geophysical Union, Joint Annual Meeting, Field Trip 7 Guidebook, 35 p.

Gadd, N.R.

- 1980: Late-glacial regional ice-flow patterns in eastern Ontario; *Canadian Journal of Earth Sciences*, v. 17, p. 1439-1453.

Geological Survey of Canada

- 1976: Airborne gamma-ray spectrometry data, Ontario-Quebec; Geological Survey of Canada, Open File 331.
1977: Airborne radioactivity maps and profiles; Geological Survey of Canada, Open File 428.
1981: National geochemical reconnaissance, 1:2 000 000 coloured compilation map series, southeastern Ontario (31C(N1/2), 31F); Geological Survey of Canada, Open File 747.

Gleeson, C.F., Rampton, V.N., Thomas, R.D., and Paradis, S.

- 1989: Effective mineral exploration for gold using geology, Quaternary geology and exploration geochemistry in areas of shallow till; in *Drift Prospecting*, (ed.) R.N.W. DiLabio and W.B. Coker; Geological Survey of Canada, Paper 89-20, p. 71-96.

Gorrell, G.A.

- 1986: Development of a subaqueous outwash fan: an example from the County of Lanark, Ontario, Canada; M.Sc. thesis, Queen's University, Kingston, Ontario, 180 p.

Harding, W.D.

- 1942: Geology of Kaladar and Kennebec Townships; Ontario Department of Mines, Annual Report, v. 51, pt. 4, p. 51-74. Accompanied by Map 51d, scale 1:63 360.
1947: Geology of the Olden-Bedford area; Ontario Department of Mines, Annual Report, v. 56, pt. 6, 100 p. Accompanied by Map 1947-5, scale 1:63 360.

Henderson, E.P.

- 1967: Surficial geology, Westport, Ontario; Geological Survey of Canada, Map 13-1965, scale 1:250 000.
1970: Map 6-1970, Surficial geology of Brockville and Mallorytown map-areas, Ontario; Geological Survey of Canada, Paper 70-18, scale 1:50 000.
1973: Surficial geology of Kingston (north half) map-area, Ontario; Geological Survey of Canada, Paper 72-48, 6 p. Accompanied by Map 7-1972 and Map 8-1792, scale 1:250 000.

Henderson, P.J.

- 1988: Sedimentation in an esker system influenced by bedrock topography near Kingston, Ontario; *Canadian Journal of Earth Sciences*, v. 25, p. 987-999.

Hewitt, D.F.

- 1964: Geological notes for Maps Nos. 2053 and 2054, Madoc-Gananoque area; Ontario Department of Mines, Geological Circular 12, 33 p. Accompanied by Maps 2053 and 2054, scale 1:126 720.

Hillefors, A.

- 1973: The stratigraphy and genesis of stoss- and lee-side moraines; *Bulletin of the Geological Institute of the University of Uppsala*, v. 5, p. 139-154.

Hornbrook, E.H.W., Kettles, I.M., and Shilts, W.W.

- 1986: Geochemistry of aquatic and terrestrial sediment, Precambrian Shield of southeastern Ontario; *Water, Air, and Soil Pollution*, v. 31, p. 969-979.

Hornbrook, E.H.W., Lund, N.G., and Lynch, J.J.

- 1984a: Regional lake sediment and water geochemical reconnaissance data, Ontario 1982, parts NTS 31C(S/2) and 31F (Ontario only); Geological Survey of Canada, Open File 899.
1984b: Regional lake sediment and water geochemical reconnaissance data, Ontario, 1982, parts of NTS 31D, 31E, and 41H; Geological Survey of Canada, Open File 900.

Jackson, M.L.

- 1956: Soil chemical analysis — advanced course — a manual of methods; University of Wisconsin, Madison, Wisconsin, 527 p.

Karboski, F.

- 1980: Structure and stratigraphy of Norcan Lake area, Grenville Province, southeastern Ontario; M.Sc. thesis, Carleton University, Ottawa, Ontario, 100 p.

Kaszycki, C.A.

- 1988: Quaternary geology and glacial history of the Haliburton region, south central Ontario, Canada: A model of glacial and proglacial sedimentation; Ph.D. thesis, University of Illinois, Urbana, Illinois, 230 p.

Kaszycki, C.A. and DiLabio, R.N.W.

- 1986: Surficial geology and till geochemistry, Lynn Lake-Leaf Rapids region, Manitoba; Geological Survey of Canada, Paper 86-1B, p. 245-256.

Kay, G.M.

- 1942: Ottawa-Bonnechere graben and Lake Ontario homocline; *Bulletin of Geological Society of America*, v. 53, p. 585-646.

Kettles, I.M.

- 1988a: Reconnaissance geochemical data for till and other surficial sediments, Muskoka region, Ontario: applications to acid rain research and mineral exploration; Geological Survey of Canada, Open File 1792.
1988b: Reconnaissance geochemical data for till and other surficial sediments, Gatineau and surrounding areas, southwestern Quebec: applications to acid rain research and mineral exploration; Geological Survey of Canada, Open File 1899.
1990: Geochemistry of glacial sediments in the Clyde Forks-Westport area, Ontario: applications to mineral exploration and acid rain research; Geological Survey of Canada, Open File 2274.

Kettles, I.M. and Shilts, W.W.

- 1983: Reconnaissance geochemical data for till and other surficial sediments, Frontenac Arch and surrounding areas, Ontario; Geological Survey of Canada, Open File 947.
1989: Geochemistry of drift over Precambrian Grenville Province, southeastern Ontario and southwestern Quebec; in *Drift Prospecting*, (ed.) R.N.W. DiLabio and W.B. Coker; Geological Survey of Canada, Paper 89-20, p. 97-112.

Leyland, J.G.

- 1984: Quaternary geology of the northeastern Lake Ontario basin; M.Sc. thesis, Brock University, St. Catharines, Ontario, 68 p.

Lumbers, S.B.

- 1982: Summary of metallogeny, Renfrew County; Ontario Geological Survey, Report 212, 58 p. Accompanied by maps 2459, 2460, 2461, and 2462, scale 1:100 000.

MacClintock, P. and Stewart, D.P.

- 1965: Pleistocene geology of the St. Lawrence Lowland; New York State Museum, Bulletin 394, 152 p.

- Mason, B.**
1962: Principles of Geochemistry; Wiley, New York, 329 p.
- Mirynech, E.**
1962: Pleistocene geology of the Trenton-Campbellford map area, Ontario; Ph.D. thesis, University of Toronto, Toronto, Ontario, 176 p.
1967: Pleistocene and surficial geology of the Kingston-Coburg-Tweed area, Ontario; in *Geology of parts of eastern Ontario and southeastern Quebec*, (ed.) S.E. Jenness; Geological Association of Canada Guidebook, p. 183-198.
- Moore, J.M.**
1982: Stratigraphy and tectonics of the Grenville orogen in Eastern Ontario; 1982 Grenville Workshop, Rideau Ferry, Abstract Volume, Friends of the Grenville, p. 7.
- Muller, E.H. and Prest, V.K.**
1985: Glacial lakes in the Ontario basin; in *Quaternary Evolution of the Great Lakes*, (ed.) P.F. Karrow and P.E. Calkin; Geological Association of Canada, Special Paper 30, p. 214-229.
- Pauk, L.**
1982: Geology of the Ardoch area; Ontario Geological Survey Open File Report 5381, 125 p. Accompanied by Preliminary Map P. 2487, scale 1:15 840.
1984a: Geology of the Dalhousie Lake area, Frontenac and Lanark counties; Ontario Geological Survey, Open File Report 5517, 116 p. Accompanied by Preliminary Map P. 2533, scale 1:15 840.
1984b: Geology of the Lavant area, Lanark and Frontenac Counties; Ontario Geological Survey, Open File Report 5519, 129 p. Accompanied by Preliminary Map P. 2610, scale 1:15 840.
1987: Precambrian geology, Ardoch area, southern Ontario; Ontario Geological Survey, Map 2514, scale 1:15 840.
- Poole, W.H., Sanford, B.V., Williams, H., and Kelley, D.G.**
1970: Geology of southeastern Canada; in *Geology and Economic Minerals of Canada*, (ed.) R.J.W. Douglas; Geological Survey of Canada, Economic Geology, No. 1, p. 227-304.
- Prest, V.K.**
1970: Quaternary geology of Canada; in *Geology and Economic Minerals of Canada*, (ed.) R.J.W. Douglas; Geological Survey of Canada, Economic Geology, No. 1, p. 676-764.
- Reinhardt, E.W.**
1973: Geology, Carleton Place; Geological Survey of Canada, Map 1362A, scale 1:50 000.
- Richard, S.H.**
1984: Surficial geology, Amprior, Ontario-Quebec; Geological Survey of Canada, Map 1599A, scale 1:50 000.
1990: Surficial deposits of Carleton Place area; Geological Survey of Canada, Map 1681A, scale 1:50 000.
- Rivers, T.**
1976: Structures and textures of metamorphic rocks, Ompah area, Grenville Province, Ontario; Ph.D. thesis, University of Ottawa, Ottawa, Ontario, 281 p.
- Rodrigues, C.G.**
1988: Late Quaternary invertebrate faunal associations and chronology of the western Champlain Sea basin; in *Late Quaternary Development of the Champlain Sea Basin*, (ed.) N.R. Gadd; Geological Association of Canada, Special Paper 35, p. 155-176.
- Rust, B.R. and Romanelli, R.**
1975: Late Quaternary subaqueous outwash deposits near Ottawa, Canada; in *Glaciofluvial and Glaciolacustrine Sedimentation*, (ed.) A.V. Jopling and B.C. McDonald; Society of Economic Paleontologists and Mineralogists, Special Publication 23, p. 177-192.
- Sanford, B.V. and Baer, A.J.**
1971: Southern Ontario, Ontario, Sheet 30S; Geological Survey of Canada, Map 1335A, scale 1:1 000 000.
- Sangster, A.L.**
1982: Geology of the Grenville Province and regional metallogenesis of the Grenville Supergroup; in *Precambrian Sulphide Deposits*, H.S. Robinson Memorial Volume, (ed.) R.W. Hutchinson, C.D. Spence and J.M. Franklin; Geological Association of Canada, Special Paper 25, p. 91-125.
- Sharpe, D.R.**
1979: Quaternary geology of the Merrickville area; Ontario Geological Survey, Report 180, 54 p.
- Shaw, J.**
1988: Subglacial erosional marks, Wilton Creek, Ontario; Canadian Journal of Earth Sciences, v. 25, p. 1256-1267.
- Shilts, W.W.**
1973: Drift prospecting; geochemistry of eskers and till in permanently frozen terrain, District of Keewatin, Northwest Territories; Geological Survey of Canada, Paper 72-45, 34 p.
1975: Principles of geochemical exploration for sulphide deposits using shallow samples of glacial drift; Canadian Mining and Metallurgical Bulletin, v. 68, p. 73-80.
1981: Sensitivity of bedrock to acid precipitation: modification by glacial processes; Geological Survey of Canada, Paper 81-14, 7 p.
1984a: Potential effects of acid rain on glaciated terrain; in *Groundwater as a Geomorphic Agent*, (ed.) R.G. LaFleur; Binghamton Symposia in Geomorphology, no. 13, Allen and Unwin, Boston, p. 135-156.
1984b: Till geochemistry in Finland and Canada; Journal of Geochemical Exploration, v. 21, p. 95-117.
- Sinclair, I.G.L.**
1979: Geochemical investigation of the Clyde River zinc prospect, Lanark County, Ontario, in *Geochemical Exploration 1978*, (ed.) J.R. Watterson and P.K. Theobald; Association of Exploration Geochemists, p. 487-495.
- Smith, B.L.**
1958: Geology of the Clarendon-Dalhousie area; Ontario Department of Mines, Annual Report for 1956, v. 65, pt. 7, p. 1-47. Accompanied by Map 1956-4, scale 1:63 360.
- Spencer, J.W.W.**
1890: The deformation of Iroquois Beach and birth of Lake Ontario; American Journal of Science, v. 40, p. 433-451.
- Terasmae, J.**
1965: Surficial geology of the Cornwall and St. Lawrence Seaway Project Areas, Ontario; Geological Survey of Canada, Bulletin 121, 54 p.
- Thorleifson, L.H. and Kristjansson, F.J.**
1988: Stratigraphy and visible gold content of till in the Beardmore-Geraldton area, northern Ontario; in *Current Research, Part C*; Geological Survey of Canada, Paper 88-1C, p. 217-221.
- Wilson, M.E. and Dugas, J.**
1961: Geology of Perth, Ontario; Geological Survey of Canada, Map 1089A, scale 1:63 360.
- Wolff, J.M.**
1982a: Geology of the Kaladar area; Ontario Geological Survey Report 215, 94 p. Accompanied by Map 2432, scale 1:31 680.
1982b: Geology of the Long Lake area; Ontario Geological Survey Report 216, 76 p. Accompanied by Map 2449, scale 1:31 680.
1985: Geology of the Sharbot Lake area; Ontario Geological Survey, Report 228, 70 p. Accompanied by Map 2471, scale 1:31 680.
- Wynne-Edwards, H.R.**
1967: Westport map-area, Ontario, with special emphasis on the Precambrian rocks; Geological Survey of Canada, Memoir 346, 142 p.

**MAPS
NOT
FILMED**

**CARTES
OMISES**